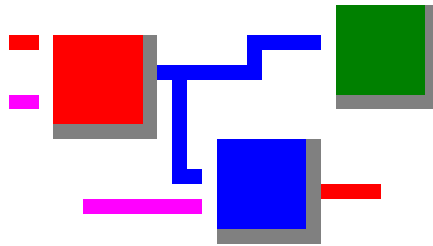


RS MINERVE



RS MINERVE - User's Manual v1.18

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For Software version 1.3.1.0

Centre de recherche sur l'environnement alpin (CREALP)



HydroCosmos SA



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Foreword

RS MINERVE is a software for the simulation of free surface run-off flow formation and propagation. It models complex hydrological and hydraulic networks according to a semi-distributed conceptual scheme. In addition to particular hydrological processes such as snowmelt, glacier melt, surface and underground flow, hydraulic control elements (e.g. gates, spillways, diversions, junctions, turbines and pumps) are also included.

The global analysis of a hydrologic-hydraulic network is essential in numerous decision-making situations such as the management or planning of water resources, the optimization of hydropower plant operations, the design and regulation of spillways or the development of appropriate flood protection concepts. RS MINERVE makes such analyses accessible to a broad public through its user-friendly interface and its valuable possibilities. In addition, thanks to its modular framework, the software can be developed and adapted to specific needs or issues.

RS MINERVE contains different hydrological models for **rainfall-runoff**, such as **GSM**, **SOCONT**, **SAC-SMA**, **GR4J** and **HBV**. The combination of hydraulic structure models (reservoirs, turbines, spillways,...) can also reproduce complex hydropower schemes. In addition, a **hydropower model** computes the net height and the linear pressure losses, providing energy production values and total income based on the turbine performance and on the sale price of energy. A **consumption model** calculates water deficits for consumptive uses of cities, industries and/or agriculture. A **structure efficiency model** computes discharge losses in a structure such a canal or a pipe by considering a simple efficiency coefficient.

The **RS Expert module**, specifically created for research or complex studies, enables in-depth evaluation of hydrologic and hydraulic results. **Time-slice simulation** facilitates the analysis of large data sets without overloading the computer memory. **Scenario simulation** introduced the possibility of simulating multiple weather scenarios or several sets of parameters and initial conditions to study the variability and sensitivity of the model results. The **automatic calibration** with different algorithms, such as the SCE-UA, calculates the best set of hydrological parameters depending on a user-defined objective function.

RS MINERVE program is **freely distributed** to interested users. Several projects and theses have used and are using this program for study basins in Switzerland, Spain, Peru, Brazil France and Nepal. In addition to the research center **CREALP** and the engineering office **HydroCosmos SA**, which currently develop RS MINERVE, two universities (**Ecole Polytechnique Fédérale de Lausanne** and **Universitat Politècnica de València**) collaborate to improve RS MINERVE and use it to support postgraduate courses in Civil Engineering and Environmental Sciences. Other collaborations, such as with the **Hydro10 Association**, complement and enhance the development of RS MINERVE.

Chapter 1: Introduction

RS MINERVE is based on the same concept than Routing System II, earlier software developed at the Laboratory of Hydraulic Constructions (LCH) at the Ecole Polytechnique Fédérale de Lausanne (EPFL) (Dubois et al., 2000; García Hernández et al., 2007) and used since 2002 in different projects and theses, such as by Jordan (2007) or Claude (2011).

The software presented hereafter, RS MINERVE, is currently developed by the CREALP and HydroCosmos SA, with the collaboration of the previously mentioned LCH as well as the Universitat Politècnica de València (UPV). It has also been used since 2011 in numerous projects and theses (e.g. García Hernández, 2011).

This first chapter contains the structure of the manual, the procedure to install and update RS MINERVE and the overview of the RS MINERVE window.

1.1 Document structure

The manual is composed of nine main chapters:

1. Introduction
2. Hydrological models
3. Database
4. Simulation
5. Model calibration
6. Hydraulic structures
7. RS Expert
8. RS GIS
9. Examples of application

In the different chapters, actions to be done by the user are presented in blue.

After the bibliography, the appendix presents in detail the different parameters and initial conditions of the hydrological models available in RS MINERVE. In addition to this User's manual, the reader can also find all model equations and file descriptions in the technical manual (García Hernández et al., 2015)

1.2 Installation procedure

Proceed as follows to install RS MINERVE on your computer (requires Windows 7 or later versions of Windows):

- Visit the CREALP website: <http://www.crealp.ch>
- Go to **Resources -> Software -> RS MINERVE -> Download**
- Click on *Download page: RS MINERVE*
- Save the file, double-click on *Setup.exe* (in the Internet browser *Downloads* frame) and follow the installation procedure.
- Read and accept the *Terms and conditions for use of RS MINERVE software*.
- Click on *Install*.

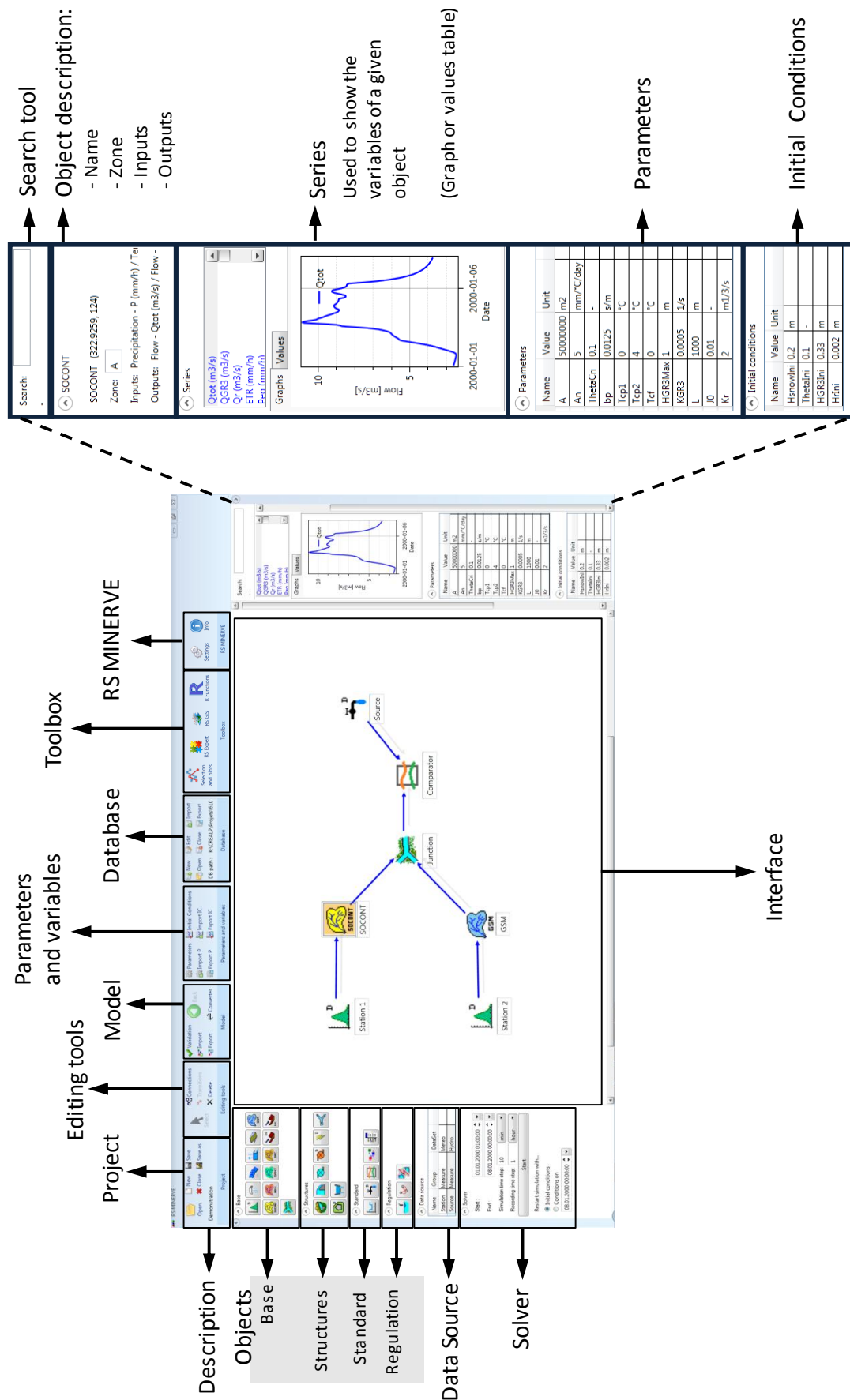


Figure 1 Structure of the RS MINERVE main window

1.3 Updates

When RS MINERVE is opened and if an Internet connection is available, RS MINERVE connects to the server to check if a new version is available. If this is the case, the user is invited to install the new version by accepting the update.

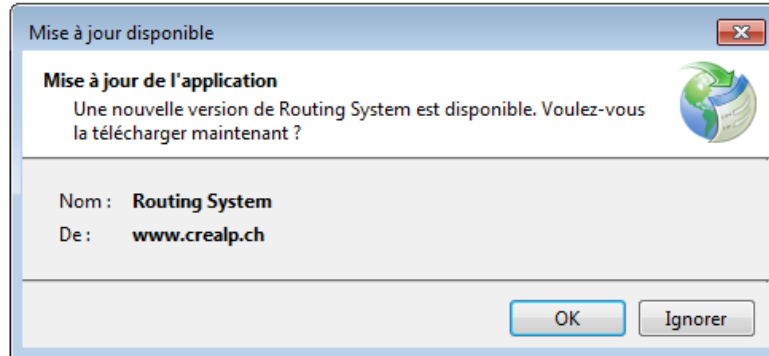


Figure 2 Installation of updates

1.4 Uninstallation procedure

To uninstall RS MINERVE, use the conventional uninstallation procedure in Windows.

1.5 The RS MINERVE main window

The structure of the RS MINERVE main window and the different frames composing it are presented in

Figure 1.

The *Interface* frame (

Figure 1) in the middle of the RS MINERVE window allows the visualization of the model network.

Interaction within the *Interface* is possible with the mouse.

- Use the scroll wheel to zoom in / zoom out
- Press the scroll wheel and move the mouse to move the interface window
- Left click on an object (Figure 3 (b)) -> Select the object and move it in the interface
- Double-click on an object (the object is highlighted, Figure 3 (c)) -> Display the *Object description*, *Series* and other corresponding frames (in the right part).

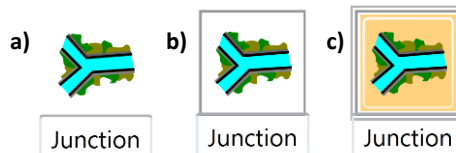


Figure 3 Example of an unselected object (a), after a left click (b) and after a double-click (c)

1.6 The Search tool

To facilitate navigation in the main window, the *Search* tool (right-frame) allows the user to enter the name of an object. All corresponding names are listed and a click on the correct one opens the parent model and highlights the corresponding object.

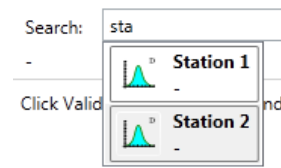


Figure 4 The Search tool

1.7 Settings

The user can access to the settings in the RS MINERVE frame (Figure 5) and can change the following values:

- The units of inputs, parameters and state variables of RS MINERVE (Precipitation, Temperature, Length, Height,...)
- The interpolation method for meteorological values:
 - Thiessen polygons: for using the nearest meteorological station
 - Shepard method: for values depending on inverse distance weighting
- The Potential Evapotranspiration (ETP) method used in the hydrological model. The ETP can be directly taken from Database, or computed with one of the following methods:
 - Turc
 - McGuinness
 - Oudin
 - Uniform ETP

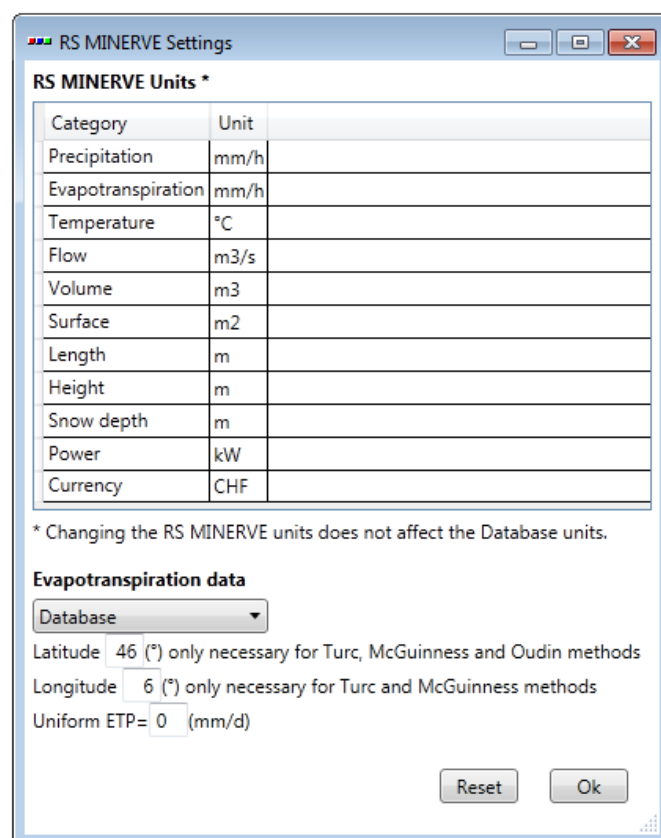


Figure 5 RS MINERVE Settings window

The settings are saved in the user's computer and are kept when the program is opened again.

1.8 List of keyboard shortcuts and mouse actions

The user can use a list of keyboard shortcuts (Table 1) as well as a list of mouse actions over the graphics (

Table 2).

Table 1 List of keyboard shortcuts

Ctrl + N	New Project
Ctrl + O	Open Project
Ctrl + S	Save Project
Ctrl + Shift + S	Save as Project
Ctrl + W	Close Project
F5	Start Simulation
Shift + F5	Stop Simulation

Esc	Back (go to hierarchical higher level), Cancel object selection (when object type selected in Objects frame)
Space	Switch between <i>Select</i> and <i>Connections</i>
Ctrl + Space	Switch between <i>Select</i> and <i>Transitions</i> (in a Regulation object only)
Ctrl	To select more than one object or series

Table 2 List of mouse actions in graphics

<i>Over the axes</i>	
Left click	-
Right click and move the mouse	Displace the current view
Move the scroll wheel	Zoom in / zoom out
Click on scroll wheel and move the mouse	Select the zoom zone
Double click on scroll wheel	Back to default zoom
<i>Over the time series plot</i>	
Left click	Date and value of the nearest series point
Right click and move the mouse	Displace the current view
Move the scroll wheel	Zoom in / zoom out
Click on scroll wheel and move the mouse	Select the zoom zone
Double click on scroll wheel	Back to default zoom

Chapter 2: Hydrological models

RS MINERVE is an object-oriented modeling software. The different processes are modeled with equation-based objects, presented hereafter in Chapters 2.1 (*Base objects*) and 2.2 (*Standard objects*). *Hydraulic structures* and *Regulation* objects are presented in Chapter 6.

The implemented hydrological models (Snow-GSM, Glacier-GSM, GR3, SWMM and GSM-SOCONT) have been developed within the framework of different research projects, namely CRUEX (Bérod, 1994), SWURVE (Schäfli & al., 2005) and MINERVE  ¹ (Hamdi & al., 2003, 2005).

The hydrological models HBV (Bergström 1976, 1992), GR4J (Perrin et al., 2003) and SAC (Burnash, 1995) are also included in the software RS MINERVE for extending the hydrological modeling possibilities.

2.1 Base objects

The *Base objects* are mostly composed of the hydro-meteorological objects. For more details, see the Technical Manual.



Virtual weather station - It calculates the local meteorological conditions (precipitation (P), temperature (T) and potential evapotranspiration (ETP)) based on observed or forecasted data from the database and based on Thiessen or Shepard interpolations. In addition, the ETP can be also calculated either with a constant value or from one of the different equations proposed by Turc (1955, 1961), McGuinness et Bordne (1972) or Oudin (2004). The method can be selected in the Settings (see chapter 1.6). For more details, please refer to the Technical Manual of RS MINERVE (García et Hernández al., 2015).



Snow-GSM - Simulates the time evolution of the snow pack based on temperature (T) and precipitation (P). The output is an equivalent precipitation (P_{eq}) and the snow height (H) proposed as input to other models such as *Infiltration (GR3)*, *Glacier-GSM* or *SOCONT*.



Glacier-GSM - It calculates the volume of melt flow from the glacier based on temperature (T) and snow height H_{snow} (snow melt for $H_{snow} > 0$ and ice melt when $H_{snow} = 0$).



Infiltration (GR3) - It determines the part of the gross rainfall which participates in the runoff as net rainfall (i_{Net}) and the part stored in the soil producing the base flow.

¹ MINERVE: Modélisation des Intempéries de Nature Extrême du Rhône Valaisan et de leurs Effets (Modeling of Rhone extreme floods in Valais and their consequences).



Runoff (SWMM) - The runoff-based hydrograph is calculated with this object from a net rainfall (i_{Net}).



GSM (Glacial Snow Melt) - The GSM object combines, in RS MINERVE, the Snow-GSM and Glacier-GSM models (Figure 6).

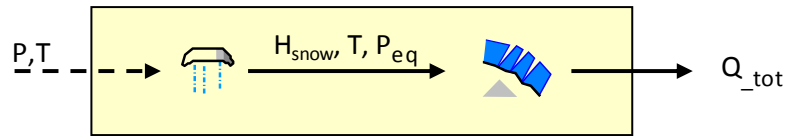


Figure 6 Composition of the GSM object



SOCONT (Soil CONTRIBUTion) - The SOCONT object combines, in RS MINERVE, the Snow-GSM, Infiltration (GR3) and Runoff (SWMM) models (Figure 7).

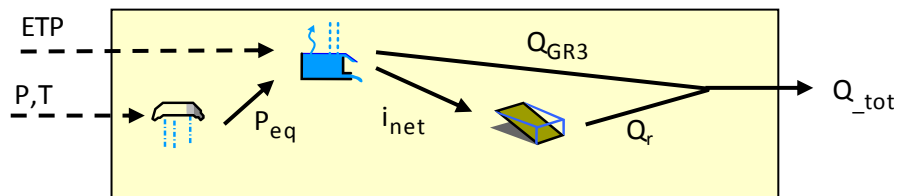


Figure 7 Composition of the SOCONT object

The parameters of the *SOCONT* and *GSM* objects are the sum of parameters of the objects composing their combinations. The behavior of the *GSM* and the *SOCONT* objects and their respective combination is therefore equivalent.



HBV - This integrated rainfall-runoff model is based on the HBV model. Using a precipitation (P), a temperature (T) and a potential evapotranspiration (ETP) as inputs, it produces a total discharge (Q_{tot}) composed of a run-off flow (Q_r), an interflow (Q_u) and a baseflow (Q_b).



GR4J - This object is based on the GR4J model, containing 4 parameters. Using an equivalent precipitation (P_{eq}) and a potential evapotranspiration (ETP) as inputs, an outflow is calculated.



SAC - The SAC-SMA (Sacramento-Soil Moisture Account) object uses an equivalent precipitation (P_{eq}) and a potential evapotranspiration (ETP) as inputs and provides an outflow at the outlet of the subbasin.



Channel reaches - The flow is transferred based on the Kinematic and Muskingum-Cunge (1969, 1991) equations.



Junction - This object allows calculating the addition of different flow inputs (also coming from hydraulic structures).

2.2 Standard objects

The *Standard objects* are complementary but generally necessary for feeding, structuring and calibrating the model.



Time series - Data can be provided to the model as time series (time in seconds). Data of any type (Flow, Temperature, Precipitation, ETP,...) can be directly transferred to other objects.



Source - Data can be also loaded from a database. *Sources* are mostly used to define flow time series for turbine or pump flow and as reference flow for calibration (with a *Comparator* object).



Comparator - This object is used to compare the results of a simulation with a reference data coming from another object, generally a *Source*. Both objects are connected to the *Comparator* for results comparison.



Submodel - A combination of objects can be saved as a submodel and integrated as such in a model.



Group Interface - It allows transferring the input or output variables between different hierarchical levels.

For hydraulic structures objects and regulation objects, please refer to Chapter 6.

2.3 Creation of a hydrological model

The steps to create a hydrological model for a natural basin (without hydraulic structures) are presented in this chapter.

To create the model

- Open RS MINERVE.
- Click on the type of object to be added (*Objects* frame,
- Figure 1). With the pencil, click in the *Interface* to add the object. Repeat the operation for all objects. If the wrong object is selected in the *Objects* frame, use the *Esc* key to cancel.
- Select *Connections* in the *Editing tools* frame (
- Figure 1) or press the *space* key to switch, interconnect the objects with blue arrows in the sense of flow and select the variables(s) concerned by the connections in the pop-ups (Figure 8). ²
- Choose *Select* in the *Editing tools* frame or press the *space* key to switch.
- By clicking on each object separately,
 - Rename the objects.
 - Modify their fixed parameters (such as coordinates for the Station and surface for main hydrological objects) in the *Parameters* frame (
 - Figure 1). See Appendix 1 for a complete list of parameters and initial conditions.

² In absence of water flow, connect arrows in the sense of information transfer.

- Define the *Zone* of each object in the *Object* frame (
 - Figure 1).³
- Use “Tab” to validate the *Zone* number.

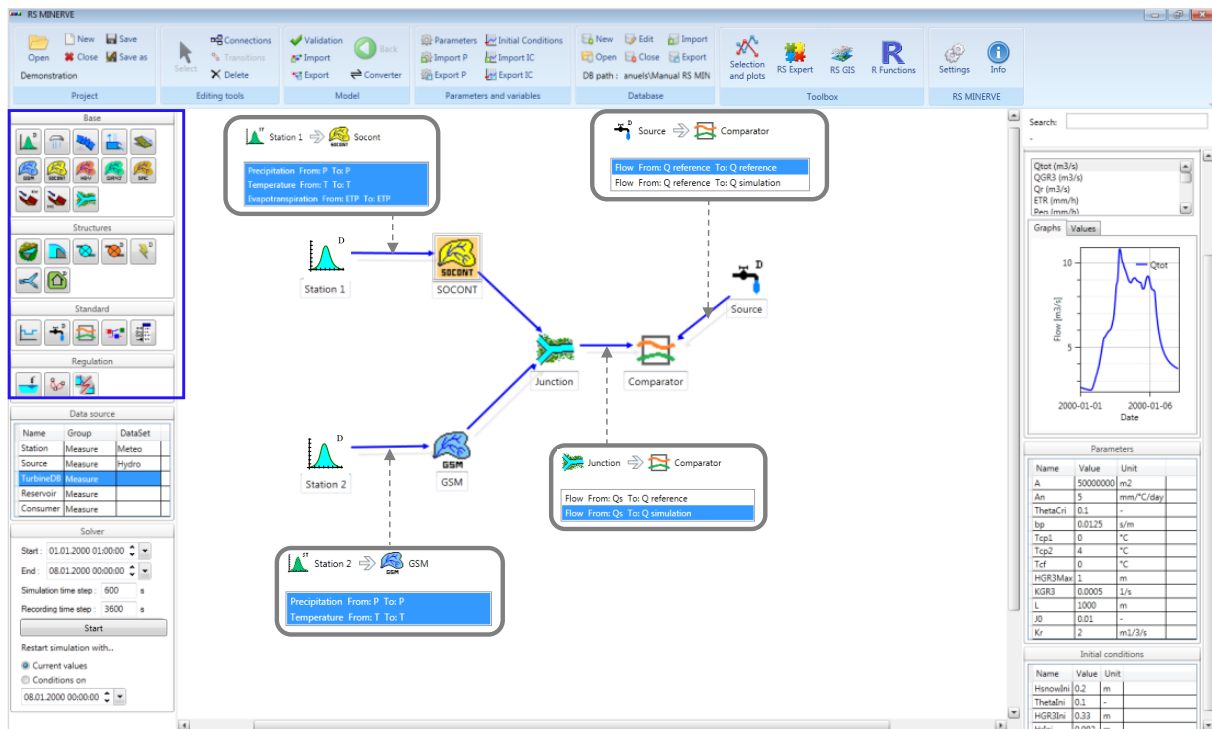


Figure 8 Example of a simple model

To define the *Parameters* of the model objects:

- Click on *Parameters* in the *Parameters and Variables* frame (
 - Figure 1).
 - Select an *Object* type and a *Zone Id* in the *Selection* frame (Figure 9). Use *Ctrl* to select more than one *Zone ID*.
- In the *Parameters management* frame (Figure 10, left), the parameters of the selected object type are listed. Parameters with identical value in all objects of the selected zone(s) are checked by default. The objects contained in the zone(s) and their respective parameter values are displayed in the *Objects list* (Figure 10, right).
- Define the parameters to be calibrated, i.e. uniformly modified, by checking and unchecking the parameters in the *Parameters management* frame (the [x] column, Figure 10, left).
 - Modify in the *Parameters management* frame the values of the *Parameters* to be calibrated and click on *Apply selected changes*. (Alternatively, individually modify the values of each object in the *Objects list* (Figure 10, right)).
 - Repeat the procedure for all object types in each zone.

³ The concept of *Zones* allows the modification of a parameter or initial condition to all the objects contained in the selected zone(s) by attributing a unique value.

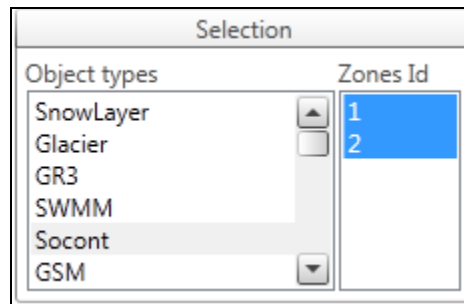


Figure 9 Selection frame

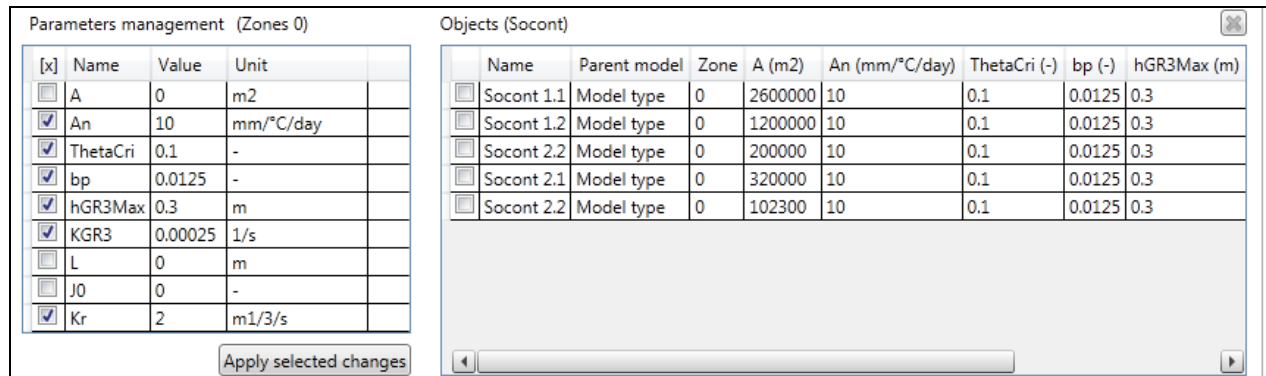


Figure 10 Left: Parameters management frame; Right: Objects of the selected zone(s) and their parameters

To define the *Initial Conditions*:

- Click on *Initial Conditions* in the *Parameters and Variables* frame (
- Figure 1).
- Proceed in a similar way than for the *Parameters* definition to modify all the *Initial Conditions*.

Initial conditions are generally not known precisely. Approximated values can be entered to improve the simulation results. Final conditions of a previous simulation ending at the start time of the period of interest can be used as current initial conditions to improve the results.

To save the project:

- Click on *Save* in the *Project* frame (
- Figure 1).
- Define the file name and save.

2.4 Exportation of a submodel

Combinations of objects can be exported and later imported as *Submodel* objects in a complete model. This allows the structuration of the model by organizing it in different hierarchical levels.

- Add a  *Group Interface* to the combination of objects to be exported.  ⁴

⁴ Group Interfaces are required to assemble a submodel with the upper hierarchical level. It allows transferring the input and/or output variables.

- Link the output object of the model (*Junction* in Figure 11) to the *Group Interface*. Select the link(s) to be created in the pop-up (*Flow* in the example of Figure 11). ⁵

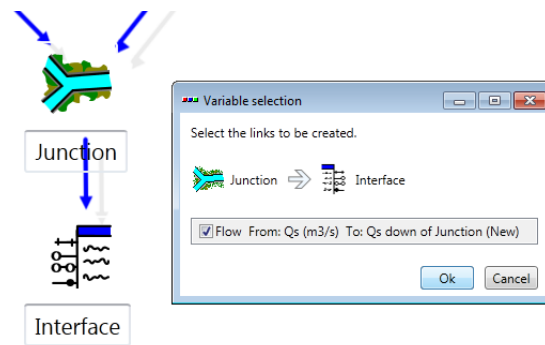


Figure 11 Addition of a *Group Interface* to the combination of objects to be exported as submodel

- Export the active model with the  *Export* button in the *Model* frame (Figure 1). ⁶
- Create a new project with the *New* button in the *Project* frame. ⁷
- Import the *Submodel* with the  *Import* button in the *Model* frame.
- Open the *Submodel* with a right-click on it. The model previously created appears.
- Return to the upper hierarchical level with the  *Back* button (*Model* frame) or by pressing the *Esc* button.
- Add a *Junction* object and link the *Submodel* to the new *Junction* (Figure 12). In the example of Figure 12, the flow of the new *Junction* now corresponds to the flow of the *Junction* in the *Submodel*.

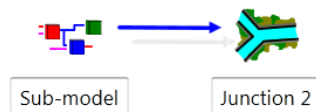


Figure 12 Link the *Submodel* to a *Junction*

At the same time, if a *Submodel* receives also an input from upstream, a second *Group Interface* has to be added in the *Submodel* and linked to the object receiving the incoming variables. *Group Interfaces* can support more than one variable as input and/or as output.

Submodels can also be created by adding an empty  *Submodel* object ⁸ and then adding the adequate objects in the *Submodel* (opened with a right-click). In a similar way, objects can be added to or deleted from imported *Submodels*.

Modifying the *Zone* of a *Submodel* modifies the zone of all the objects contained in the *Submodel*.

⁵ If only one link can be created, it is selected by default. If more than one link is possible, none is selected.

⁶ During the exportation, only the elements contained in the active hierarchical level, including all the submodels and objects, are considered. Hierarchically higher elements are not exported.

⁷ Or, alternatively, open a project with Project -> Open.

⁸ By selecting *Submodel* in the *Standard objects* frame and adding the object in the *Interface*.

2.5 Model conversion

The conversion between different hydrological models is possible with the button  **Converter** of the Model frame (Figure 13).

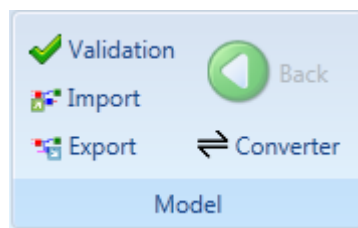


Figure 13 Model frame

The model conversion is direct for hydrological model conversions presented in Table 3. For achieving the conversion, initial and final hydrological model types are selected. Then, the zone(s) and the object(s) to convert are chosen (Figure 14).

In the current version, only the parameter A (Surface) is transferred to the new model. All other parameters are fixed to the by default values of each model.

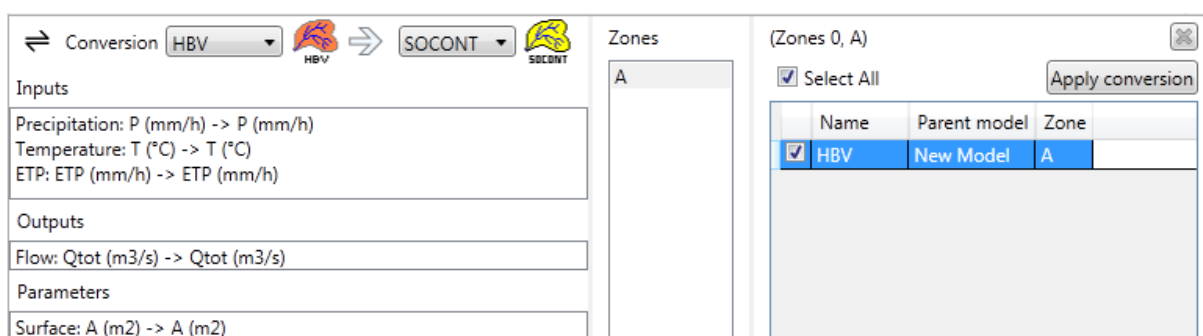


Figure 14 Example of a conversion between HBV and SOCONT

If the converted model does not need all inputs, a message informs that one of the inputs is deleted, as presented in Figure 15 for the input *Temperature*.

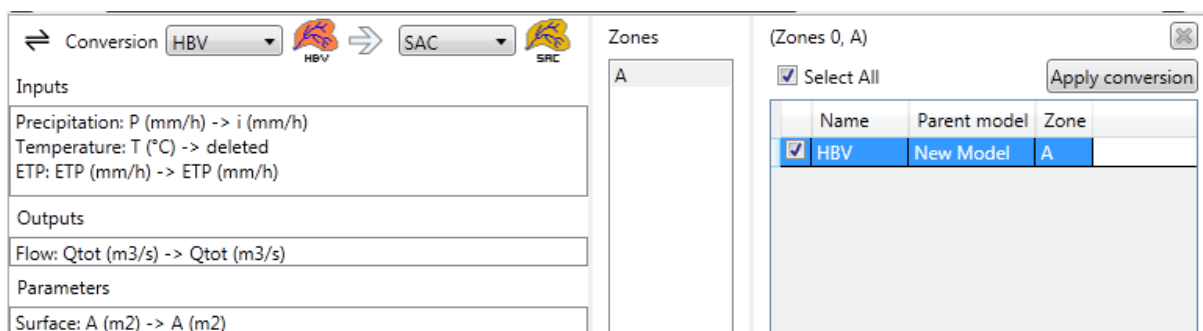


Figure 15 Example of a conversion between a model HBV and SAC, where the input *Temperature* is deleted

Finally, if the converted model needs more inputs than the original one, a message informs that one or several inputs need to be added, as presented in Figure 16 for the input *Temperature*. In that case, the link between the stations and the model needs to be replaced (or, if the data comes from a different *Station* or *Time Series*, a new link has to be added).

Conversion: SAC → HBV

Inputs

- Precipitation: i (mm/h) → P (mm/h)
- ETP: ETP (mm/h) → ETP (mm/h)
- Temperature: to implement → T (°C)

Outputs

- Flow: Qtot (m3/s) → Qtot (m3/s)

Parameters

- Surface: A (m2) → A (m2)

Zones

- A

(Zones 0, A)

☒ Select All Apply conversion

	Name	Parent model	Zone
☒	SAC	New Model	A

Figure 16 Example of a conversion between a model SAC and HBV, where the input Temperature has to be implemented by the user

Regarding the outputs, the total discharge (Qtot or Q depending on the model) is directly linked to the downstream object after the conversion.

If any other discharge is linked downstream, e.g. the Qr in the SOCONT model to a junction, the link is deleted after conversion.

Table 3 Direct conversions between objects

Object	Inputs		Object	Inputs
Glacier-GSM	 P and T	➡	GSM	 P and T
GR3	 P and ETP	➡	GR4J	 P and ETP
			SAC	 P and ETP
			SWMM	 P
SWMM	 P	➡	No direct conversions	
GSM	 P and T	➡	GSM	 P and T
			GSM	 P and T
			GR3	 P and ETP
			GSM	 P and T
SOCONT	 P, T, ETP	➡	HBV	 P, T, ETP
			GR4J	 P and ETP
			SAC	 P and ETP
			SWMM	 P
			GSM	 P and T
			GR3	 P and ETP
			GSM	 P and T
HBV	 P, T, ETP	➡	SOCONT	 P, T, ETP
			GR4J	 P and ETP
			SAC	 P and ETP
			SWMM	 P
GR4J	 P and ETP	➡	GR3	 P and ETP
			SAC	 P and ETP
			SWMM	 P
SAC	 P and ETP	➡	GR3	 P and ETP
			GR4J	 P and ETP
			SWMM	 P

Chapter 3: Database

The different input data as well as exported results are managed within a database. The *RS Database* tool, accessible from the *RS MINERVE* window, is used to create or edit the database linked to the active model.

3.1 The *RS Database* tool

The *RS Database* tool window appears when a database is created ( *New*) or opened for edition ( *Open* and then  *Edit*).

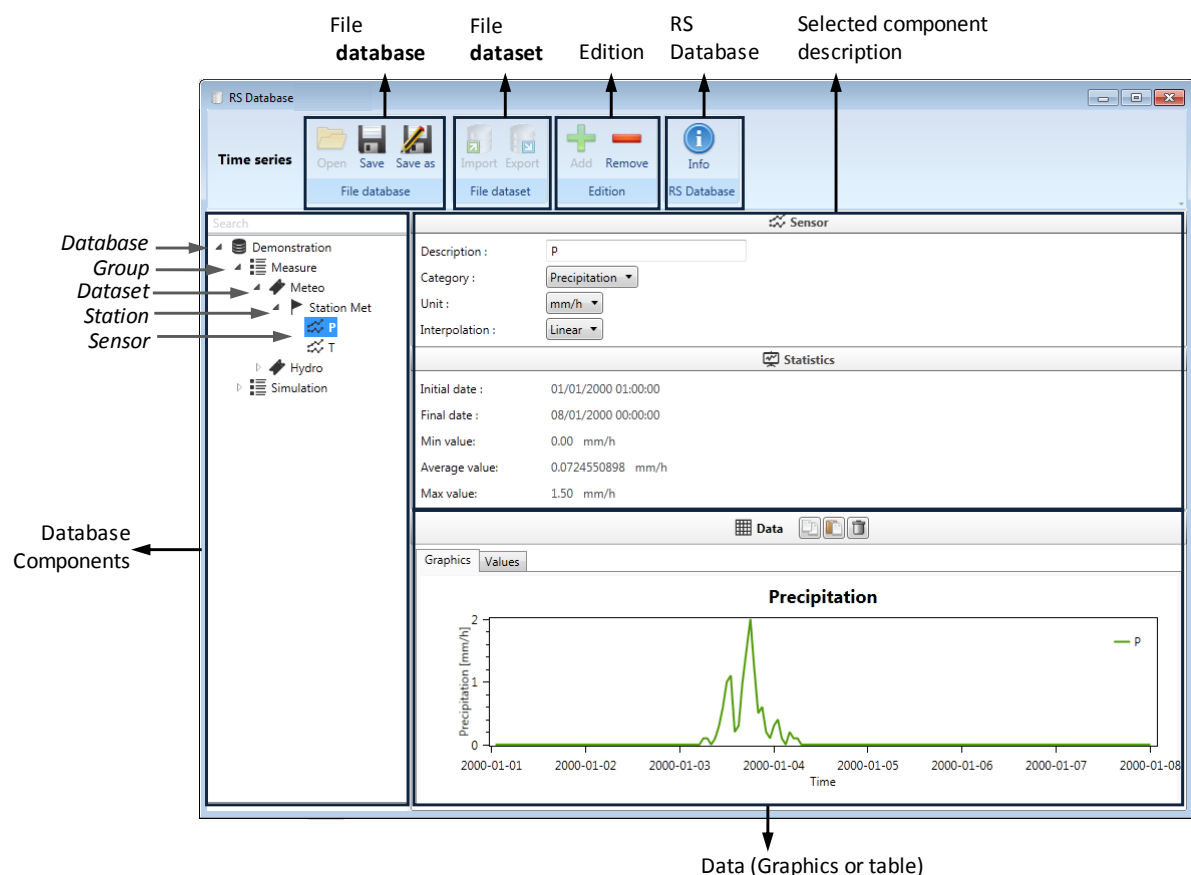


Figure 17 The *RS Database* window

The database structure is organized in five hierarchical levels, listed hereafter.

- **Database** Description of the database, complete set of data
- **Group** Separation based on category of data (Measures, Forecasts, Simulations,...) 
- **Dataset** Set of data of common type (Meteo data, Flow data,...) 
- **Station** Information about the station (name and coordinates)
- **Sensor** Description of the sensor (name, units and data)

⁹ Definition and use of *Groups* and *Datasets* can also be done in a different way by the user.

3.2 Creation of a database

The creation of a new database can be achieved following next steps:

- Click on  *New* in the *Database* frame (Figure 1) and save the new database. The *RS Database* window is opened (Figure 17).
- Create the components of the different hierarchical levels of your database by using the  *Add* button (*Edition* frame).
- For the stations, give an adequate name and enter the coordinates.
- For each sensor:
 - Define the *Description* (name), *Category*, *Unit* and *Interpolation* method.
 - Select the “Values” tab and add the data with the  *Paste* button (after copying them from any spreadsheet program).
- Save the database and close the *RS Database viewer*.

The data can be managed (exported or imported) as database or as dataset.

To manage a **database**, proceed as follows:

- To save a database: Click on the *Database* component -> *File database* -> *Save as*.
- To load another database in *RS Database*:
 - Close *RS Database*
 - Then, in the *RS MINERVE* window, click on  *Close* in the *Database* frame.
 - Click on  *Open* in the *Database* frame to open the new database.
 - Click on  *Edit* in the *Database* frame to open the new database in *RS Database*.

To manage a **dataset**, perform as follows:

- To export a dataset: Click on the *Dataset* component -> *File Dataset* -> *Save*
- To import a dataset: Click on a *Group* component -> *File Dataset* -> *Import*

If a dataset contained in a database is also stored separately as a dataset (not only in the database), both have to be saved (*File database* -> *Save*; *File dataset* -> *Save*) to properly modify all the files!

3.3 Data format

For copying series values in a sensor, two columns are necessary. The first column contains the data in one of these formats:

- dd.mm.yyyy
- dd.mm.yyyy hh:mm
- dd.mm.yyyy hh:mm:ss

The second column contains the values of the series (example in Figure 18).

31.01.2000 07:00	10.3
31.01.2000 08:00	11.1
31.01.2000 09:00	11.6
31.01.2000 10:00	12.4

Figure 18 Example of data format to use in the sensors

3.4 Connection of a database to a model

Once the database is created, links between the model and the database have to be implemented. The *Data source* frame (Figure 19, left), located in the main interface and available only when a database is opened, is used for this purpose.

- Define for the *Station* and the *Source* the corresponding *Group* and *DataSet*.
- For the *Source* objects, define in the *Object description* frame the correct station under the  *Select from database* button (Figure 19, right).  ¹⁰

The name of the station appears under *Station identifier* and is stored in the model when the model is saved.

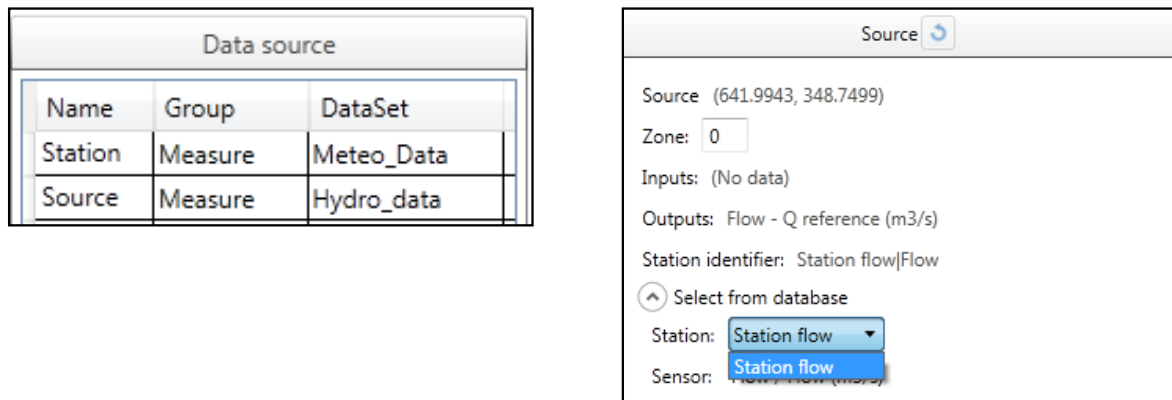


Figure 19 Left: The Data Source frame; Right: Definition of the station for objects Source

Interaction between the database and the active model

Modifications of the database in *RS Database* (without saving them!) are taken into account during simulations of the active model. However, when the database is closed, only saved changes will be applied to the database. Therefore, proper saving of the modifications is recommended.

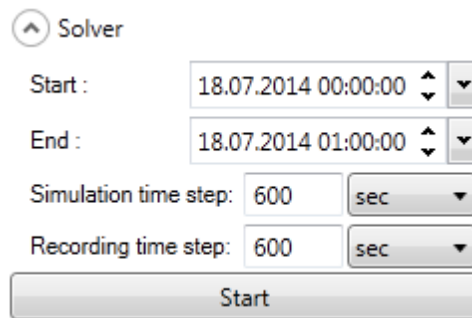
¹⁰ Source objects have to be linked to another object to define the type of output (and corresponding units) before the link to the station can be defined.

Chapter 4: Simulation

4.1 Run a model

Before solving a model, its validity has to be verified.

- Click on the  **Validation** button. A *Pre-Simulation* report is generated (right-frame).
In case of **Fatal error(s)**: Correct your model consequently.  ¹¹
In case of **Warning(s)**: Proceed to adequate modifications if required.
In case of **Note(s)**: Consider the message(s) and go ahead.
- In the *Solver* window (
- Figure 1), define the simulation period, simulation time step and recording time step (Figure 20).



The Solver window contains the following controls:

- Start**: 18.07.2014 00:00:00
- End**: 18.07.2014 01:00:00
- Simulation time step**: 600 sec
- Recording time step**: 600 sec
- Start** button

Figure 20 The *Solver* window

The time interval for the simulation time step and recording time step can be modified accordingly to Table 4.

Table 4 Possible time intervals for simulation and recording time steps

Simulation time step	Recording time step
• Seconds	• Seconds
• Minutes	• Minutes
• Hour	• Hour
• Day	• Day
	• Month

- Click on *Start*. At the end of the computation, a *Post-Simulation report* (right frame) provides a summary of the simulation with potential warning(s).
- Visualize the obtained results by selecting each object in the *Interface* and using the *Graphs* tool in the *Object* frame (
- Figure 1). Select the variable(s) of interest in the list (use *Ctrl* to select more than one series).

¹¹ During the *Validation* process, the model is verified. In particular, a *Fatal error* is generated for each missing required object's input (absence of interconnection from upstream).

4.2 Results visualization with the *Selection and Plots*

A combination of results can be visualized in the *Selection and Plots* tool.

- Click on *Selection and plots* in the *Toolbox* frame (
- Figure 1). A new window is opened.

In the *Objects and variables* frame (Figure 21), all the variables are listed by objects.

- Check in the *Objects and variables* frame the variable(s) to draw. ¹²
- Click on *Plot* to plot the listed series. ¹³
- Give a name to the active selection in the *Selections list*.
- Export the selection using *Selections* frame -> *Export*. ¹⁴
- Import a selection using *Selections* frame -> *Import*.

A second selection appears in the *Selections list*. Different selections can be defined and saved for the exploitation and analysis of the results.

Note that when *Selection and Plots* is opened, *RS MINERVE* is not active. Close *Selection and Plots* to use again *RS MINERVE*.

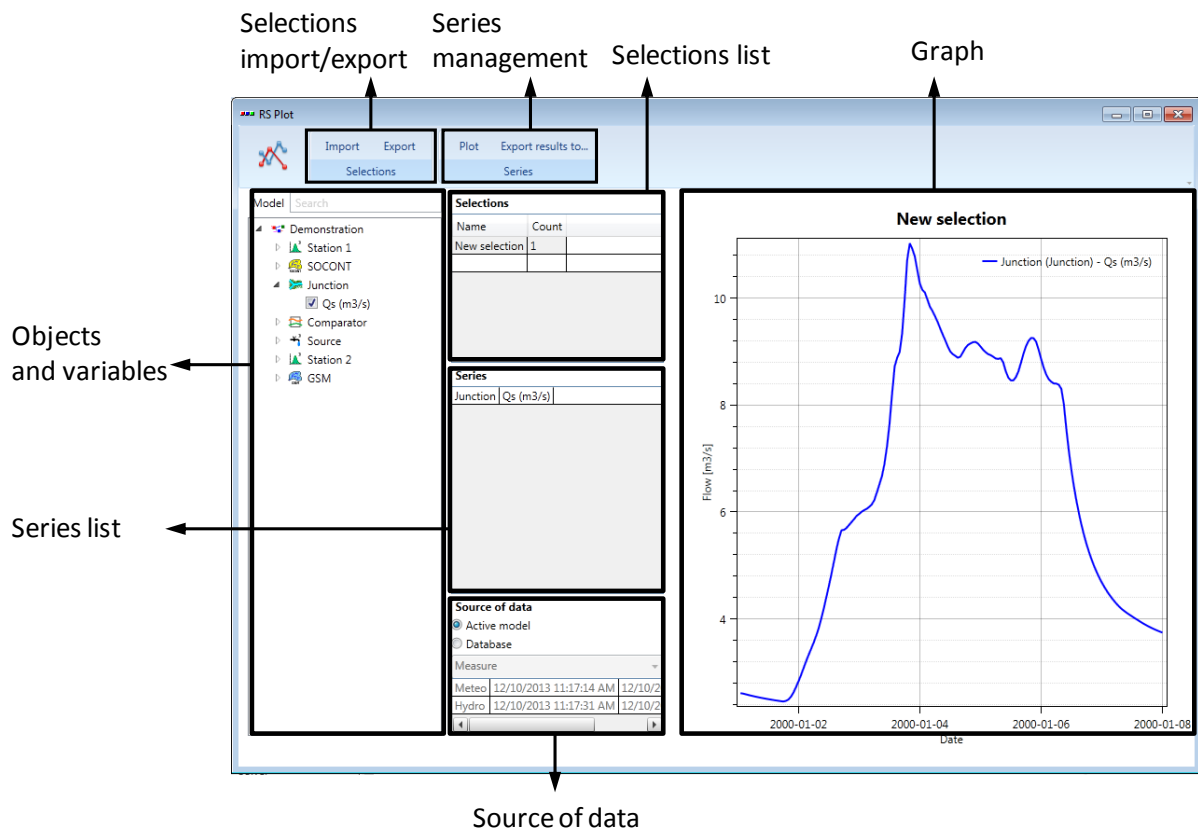


Figure 21 The *Selection and Plots* window

¹² Variables of two different units can be drawn simultaneously (second axis).

¹³ Use the mouse to visualize data values (press left button), move (press right button), zoom (press scroll-wheel) or fit to view (double-click on scroll-wheel). Zoom and fit to view can be also realised onto the axes.

¹⁴ Selections are saved in a text file with the *.chk format.

4.3 Export / Import of results to a database

Results of a simulation can be saved to the *database* as a dataset of time series.

- Select *Export* in the *Database* frame (
- Figure 1) in the RS MINERVE main window.
- Define the name of the dataset and choose between:
 - Add the dataset to an existing Group.
 - Create a new Group.
- Export with *OK*.  ¹⁵

You can now visualize your results in the database (cf. Chapter 3). Once exported, results can be imported into the model. Importing a dataset of series replaces the current time series (results of a simulation) of all concerned objects.

- Select *Import* in the *Database* frame.
- Select the *Group* and the *Dataset* of time series to import and click *Ok*.

Exported results can also be visualized in the *Selection and Plots* tool.

- Open *Selection and Plots* tool (*Toolbox* frame -> *Selection and plots*).
- In the *Source of data*, check the *Database* source (Figure 21), then select in the combo the *Group* containing the dataset of time series.
- Select the dataset of time series to be drawn.
- Click on *Plot* in the *Series* frame.

¹⁵ By activating *Only selected series*, only the series corresponding to the last active *Selection* in the *Selection and Plots* are exported.

Chapter 5: Model calibration

The calibration process aims to progressively improve the model to fit the simulated data to the reference data (e.g. the observations) by iteratively adjusting the object's parameters.

5.1 Single sub-basin calibration

To proceed to the calibration, observed data are required as comparison basis for the simulated data. Sites of measure stations generally define outlets of sub-basins since they represent the location of comparison (simulated data vs. observed data).  ¹⁶

For simplicity, division into zones generally respects the sub-basin's division. However, this is not compulsory and a zone can correspond to several sub-basins or one sub-basin can be divided into several zones. In this first part (Chapter 5.1), it is assumed that the sub-basin is composed of a single zone.

Model's performance evaluation

Before adjusting the parameters, the current performance of the model is evaluated.

- Click on the  *Comparator* object which has been added and connected as presented in Figure 8.
- In the *Series* frame (Figure 22), select $Q_{reference}$ and $Q_{simulation}$ (use *Ctrl* to select both).
- Visualize the actual results:
 - In the *Series* frame, both curves are plotted together under *Graphs*.
 - In the *Comparator* frame, seven performance indicators are provided (read the Technical Manual for more information (García Hernández et al., 2015)).
 - Nash coefficient
 - Nash-In coefficient
 - Pearson Correlation Coefficient
 - Bias Score
 - Relative Root Mean Square Error
 - Relative Volume Bias
 - Normalized Peak Error

Manual parameters adjustment

Based on the current model's performance, object's parameters can be adjusted to improve the next run's performance.

- Click on *Parameters* in the *Parameters and variables* frame (Figure 22).
- Select in the *Selection* frame (Figure 22) the type of object to be modified and the corresponding zone. See Chapter 2 for complete procedure.

¹⁶ Other factors are also considered during the basin division such as reservoir locations or river junctions.

- Modify the selection (checks) of parameters in the *Parameters Management* frame to select only the ones to be calibrated (i.e. to be uniformly modified).
- Modify the values of the selected parameters and click on *Apply selected changes*. Parameters are modified in the listed objects.
- Proceed in a similar way for all object types.
- Modify also the initial conditions to fit better the reference data.

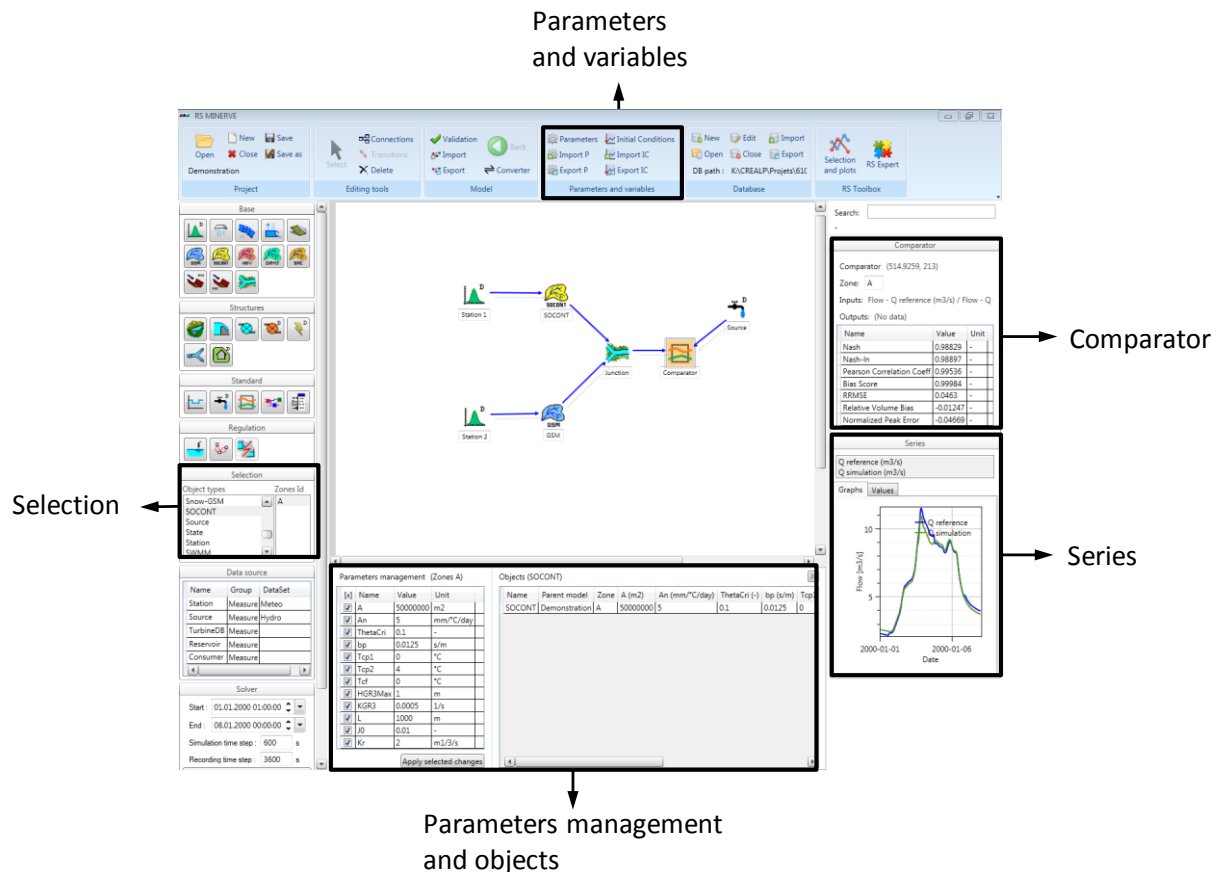


Figure 22 Frames used for the calibration

- After running the model, analyze the results in the comparator and modify again the parameters when necessary.

The procedure is iterative until the simulation results are considered sufficiently satisfying for a specified zone.

Parameters and *Initial conditions* can be exported to be, later, imported again. Use *Export P* and *Import P* for the parameters and *Export IC* and *Import IC* for the initial conditions in the *Parameters and variables* frame (Figure 22). The parameters or initial conditions can be saved as .txt file or also as .xlsx file with one sheet per object type.

Automatic parameters adjustment

An automatic calibration can be also achieved thanks to a specific module developed in RS Expert. Please the chapter 7.1 for more information.

5.2 Complete basin calibration

When a basin is composed of many sub-basins, the calibration has to be progressively achieved from upstream to downstream in the basin. By proceeding as such, contributions from the upstream calibrated sub-basin(s) are considered as input(s) to the downstream sub-basin on which the calibration is performed. Parameters are modified for the concerned sub-basin to obtain the best possible results at the outlet of the sub-basin. The calibration module (Chapter 7.1) can realize multiple calibrations for calibrating these complex basins from upstream to downstream.

Depending on the quality of the simulation results, inputs from upstream sub-basins can be replaced in the calibration process by observed data at the entrance of the sub-basin being calibrated.

Chapter 6: Hydraulic structures

Chapters 1 to 5 have presented the different steps to create a hydrological model without any hydraulic structures. Chapter 6 explains how structures like reservoirs, turbines or spillways are implemented in RS MINERVE.

Hydraulic structures are listed in Chapter 6.1 and objects used for automatic regulation are presented in Chapter 6.2.

6.1 Hydraulic structure objects



Reservoir - Water level and volume evolution are simulated based on a “Level-Volume” relation and an initial reservoir level.



HQ - Based on a level-discharge relation, it allows integration of level-based outflows to reservoirs (such as spillways, gates, orifices,...).



Turbine - It calculates the turbine or pump flow from a reservoir, based on a *Wanted Discharge* defined in a *Source* or in a *Time Series*.



TurbineDB - The TurbineDB object works as the *Turbine* object but is directly based on data provided by the database. It is equivalent to the combination of a turbine and a source.



Hydropower - This object calculates the power and the revenue, normally produced by a turbine, depending on the discharge and on the reservoir level.



Diversion - This object is used to simulate the separation of flow based on an “Inflow - Diverted flow” relation. It can be used as a hydrological object but is mostly used as a hydraulic function.



Consumer - This object simulates the consumed discharge of a user (e.g.: a village or an agricultural field) based on a series from a database or from a uniform demand.



Structure efficiency – This object computes effects of discharge losses in a structure like a canal or a pipe based on an efficiency coefficient.

6.2 Regulation objects



Sensor - *Sensors* are connected to other objects (generally reservoirs) from which they measure a particular variable to compare it to user predefined thresholds. In the case of a reservoir, water level or volume can be monitored.



Regulation - It allows loading the *Regulation* interface in which regulatory models with different *States* are developed.



State - In a *Regulation*, several *State* objects can be included to adapt the operations based on the situation. Only one *State* can be active in a *Regulation*. Transfer from one *State* to another are based on threshold values monitoring provided by *Sensors*.

6.3 Addition of a Hydropower scheme

This chapter presents a general example for the construction of a hydropower scheme, including a reservoir with a hydropower plant, a turbine and a spillway.

Addition of a reservoir

To add a reservoir:

- Select the object *Reservoir* in the *Structures objects* frame (Figure 23) and add it in the *Interface*.
- Link the output of the upstream sub-basin (object *Junction* in Figure 23) to the *Reservoir*.

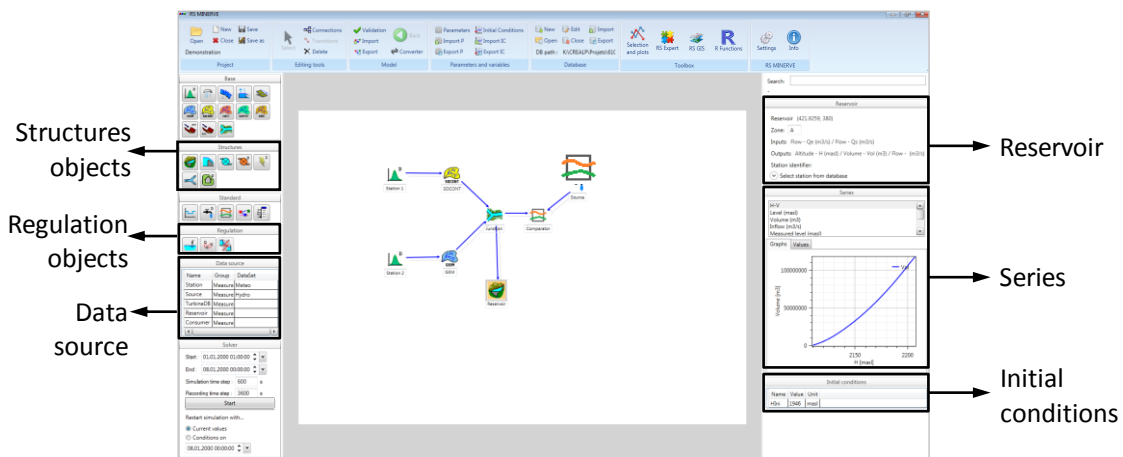


Figure 23 A regular model with a reservoir

- Double-click on the *Reservoir* object. The *Reservoir*, *Series* and *Initial Conditions* frames are opened (Figure 23).
- In the *Series* frame, select the *H-V* series and open the *Values* tab.
- By default, the table is empty. Insert the corresponding Height-Volume (*H-V*) relation for the reservoir.
- Define an initial water elevation (*H_{ini}*) in the *Initial conditions* frame.

Alternatively to the last point to define the initial water elevation of the *Reservoir*, a time series can be saved in the database with a sensor of Category *Altitude* and Unit *masl*. For each simulation, RS MINERVE will then search and interpolate the initial condition from the added time series. To link the *Reservoir* with the sensor, first select in the *Data Source* frame the corresponding *Group* and *Dataset*.

Then, in the *Reservoir* frame (right part), click on the  *Select station from Database* button and define the correct station in the *Station* drop-down list (only stations containing a sensor with appropriate units are listed). The value in the *Initial conditions* frame will change after every simulation to the value interpolated from the time series.

Once a reservoir is implemented, outputs of the reservoir have to be defined. Water from a reservoir can be exited through different ways. A combination of *Turbine* (or *TurbineDB*) and *Hydropower* objects are used to simulate the use of water for hydropower production. *Regulations* are generally used to automatize the operation of *Turbine* and *TurbineDB* objects. Finally, *HQ* objects generate discharges based on elevation-discharge relations.  ¹⁷

All these objects can be used independently and cumulatively. For example, several turbines can be placed in parallel with one or several *TurbineDB*(s), *HQ* object(s) and/or *Regulation*(s). None of them is imperative.

Addition of a TurbineDB object

The *TurbineDB* object is based on data from a database. Thus, before adding a *TurbineDB*, data have to be added to the database

- Open a database (see Chapter 3) and create a station with a sensor of category *Flow*. Modify the description and insert data for the *TurbineDB* outflow in the *Values* tab.

The *TurbineDB* object is then added.

- Select the object *TurbineDB* in the *Structures objects* frame (Figure 23) and add it in the *Interface*. Add also a *Junction* to which outflow(s) from the *Reservoir* will be linked to.
- Switch to *Connections* (*Editing Tools* frame-> *Connections* or use the *space* key) and link the *Reservoir* to the *TurbineDB* object and the *TurbineDB* object to the *Junction* (Figure 24).

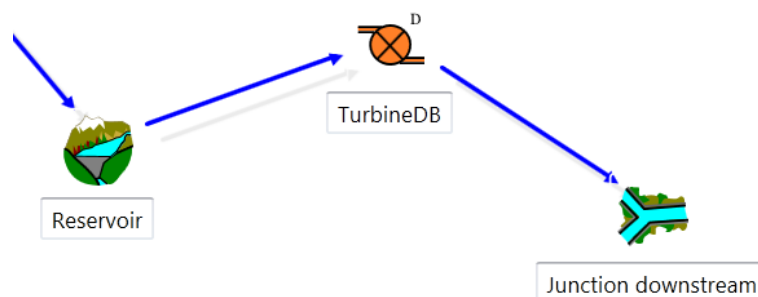


Figure 24 Addition of a *TurbineDB* and a junction

¹⁷ As outputs from the *Reservoir* are defined by downstream objects, output flows (Q_s) are considered as an *Input* to the *Reservoir* in terms of information flow. The corresponding water is thereby withdrawn from the stored volume. This implies that at least one output flow has to be defined to validate the model (See  ¹³).

- In the *Data Source* frame (Figure 23), select for the line *HPP* ¹⁸ the *Group* and *DataSet* corresponding to the sensor created in the database.
- Double-click on the *TurbineDB* object to open the *TurbineDB* frame (right-side). Then, click on the  *Select station from Database* button and define the corresponding station in the *Station* drop-down list. The link between the *TurbineDB* object and the database is now operational.

The *TurbineDB* object is ready for use.

Addition of a Hydropower object

The *Hydropower* object calculates the power and the revenue produced by the discharge of the turbine from the reservoir. The results depend on the discharge and on the reservoir water level.

- Select the object *Hydropower* in the *Structures objects* frame (Figure 23) and add it in the *Interface* (Figure 25).

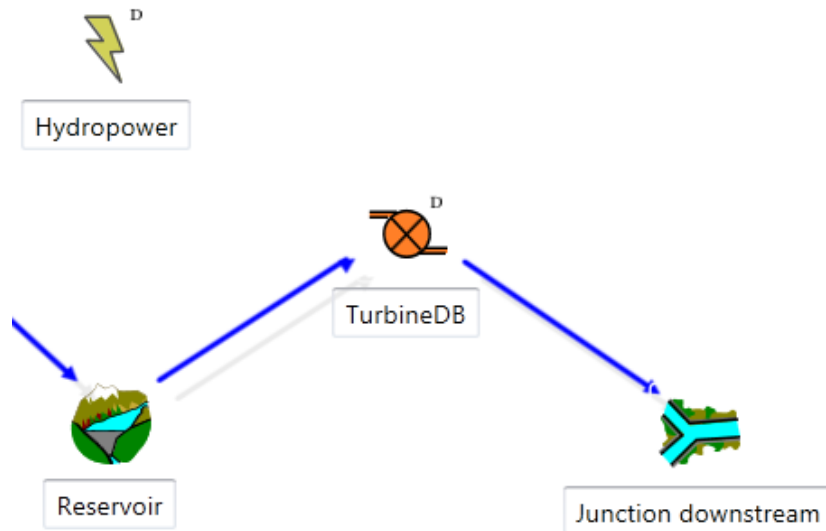


Figure 25 Addition of a *Hydropower* object

As the power produced in the hydropower plant depends on the water level in the reservoir and on the discharge of the turbine, the links between the *Hydropower* and the *Reservoir* objects, and between the *Hydropower* and the *Turbine DB* objects must be created (Figure 26).

- Link the *Reservoir* to the *Hydropower* object so the water level information can be transferred to the *Hydropower* object.
- Link the *TurbineDB* to the *Hydropower* object so the discharge variable can be transferred to the *Hydropower* object.

¹⁸ Short for HydroPower Plant, which includes the *TurbineDB* and the *Hydropower* objects.

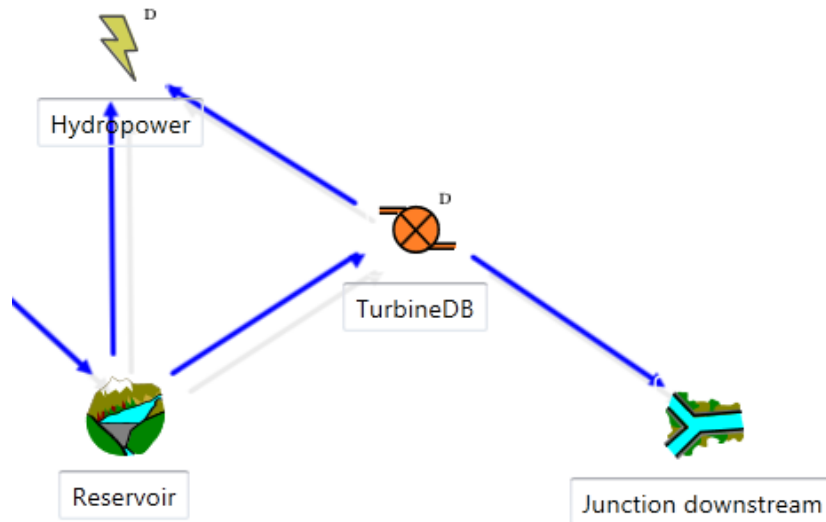


Figure 26 Links between the *Hydropower* object and the *Reservoir* and with the *TurbineDB*

- Double-click on the *Hydropower* object to open the Hydropower frame (right-side). Then, click on the *Select station from Database* button and define the corresponding station which contains the "Electricity price" series in the *Station* drop-down list. The link between the *Hydropower* object and the database is now operational.
- In the *Series* frame, select the $Q-\eta$ (discharge-efficiency) series and open the Values tab. Insert data for the $Q-\eta$ relation (manually or copied from a spreadsheet).
- In the *Parameters* frame, introduce the features of the hydropower plant. In particular the following parameters must be specified: the hydropower plant altitude (Z_{central}) in masl; the length of the pipe (L) in m; the diameter of the pipe (D) in m; the Roughness (K) in m; the kinematic viscosity (ν) in m^2/s ; and the default price of electricity, only used if no data exists in the database.

The *Hydropower* object is ready for use.

Addition of an HQ object

HQ objects are used to define level-discharge relations to implement structures such as spillways, orifices or sluice gates. For illustration purpose, an *HQ* object is used as a spillway in the following procedure.

- Select the *HQ* object in the *Structures objects* frame (Figure 23) and add it in the *Interface*.
- Link the *Reservoir* to the *HQ* object and the *HQ* object to the *Junction* (Figure 27).

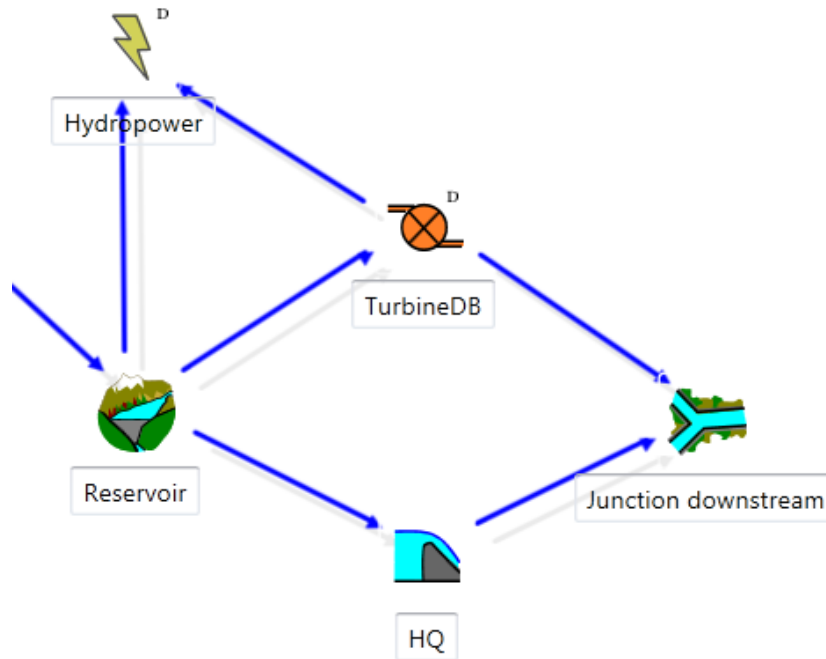


Figure 27 Addition of a spillway

- Double-click on the *HQ* object. In the *Series* frame, select the *H-Q* series and open the *Values* tab. Insert data for the *H-Q* relation (manually or copied from a spreadsheet).

The *HQ* object is ready for use.

Simulation with implemented structures

Several structures can be added in parallel as illustrated in Figure 27. When all objects are created, the model linked to the database and validated, start the simulation (Chapter 4.1). Discharges through the different objects can then be visualized by clicking on each object (Chapter 4.1) or within the *Selection and Plots* tool (Chapter 4.2).

It is **important** to remember that discharges generated by *HQ* objects are defined by the water level in the reservoir. Below a certain level, no discharge is produced. This is not the case of the *TurbineDB* objects that withdraws from the reservoir the discharges defined in the database, without checking if water is available or not in the reservoir. This might result in a negative volume in the reservoir (a warning is generated in the *Simulation report*). In order to generate discharges only when the water is actually available, *Regulation* objects are necessary.

6.4 Implementation of a regulation

Regulation objects allow the definition of automatic rules to switch between different *States* depending on the actual conditions in the system. A *State* object is similar to a submodel since several objects can be introduced in it as a function of the demands (turbine, pump, diversion, etc.). A typical example of regulation is the implementation of a turbine law as a function of the water level in the reservoir.

One or several inputs/outputs can be considered in or produced by a *State* objet. The definition of the active *State* is carried out as a function of the user predefined thresholds values monitored by the *Sensor* objects.

Addition of a regulation

The complete procedure to add and implement a *Regulation* is detailed hereafter. For illustration purpose, consider two possible *States* ("Turbine On" and "Turbine Off") for the turbine of the previous example: the turbine should turn off if the water level at the reservoir falls below 1503 [masl], and turn back on when the water level exceeds 1506 [masl], and so on.

- Delete the *Turbine DB* object of the previous example. Select the *Regulation* object in the *Regulation objects* frame (Figure 23) and add it in the *Interface*. Add a *Sensor* and link the *Reservoir* to the *Sensor* (Figure 28).

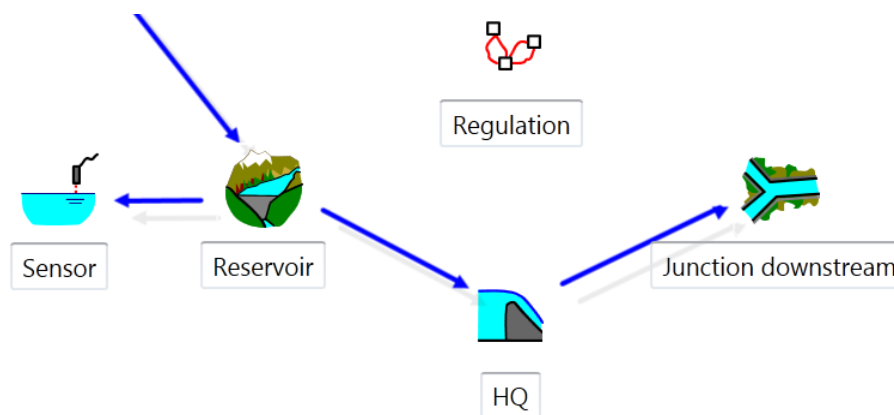


Figure 28 Objects creation for a *Regulation*

- Double-click on the *Sensor*. In the *Thresholds* frame, enter the different threshold (altitude) values in the Values column (Figure 29). The identifiers (*Id*) are automatically created for each entered value.

Thresholds		
Id	Values	
1	1503	
2	1506	

Figure 29 Example with two threshold values

Sensor objects monitor the user predefined threshold values. For each simulation time step, the threshold values are compared to the actual value of the monitored variable. Each threshold value is then characterized by *Over* or *Below* the actual level.

- Open the *Regulation* with a right-click. The empty *Regulation interface* is opened.
- Add two *Group Interfaces* and two *State* objects (Figure 30). ¹⁹ Rename the *State* objects to give them an explicit name ("Turbine On" and "Turbine Off", for instance).

¹⁹ Objects in the *Regulation interface* cannot yet be interconnected. *Group Interfaces* have first to be added in the *State* objects and connected to other objects.

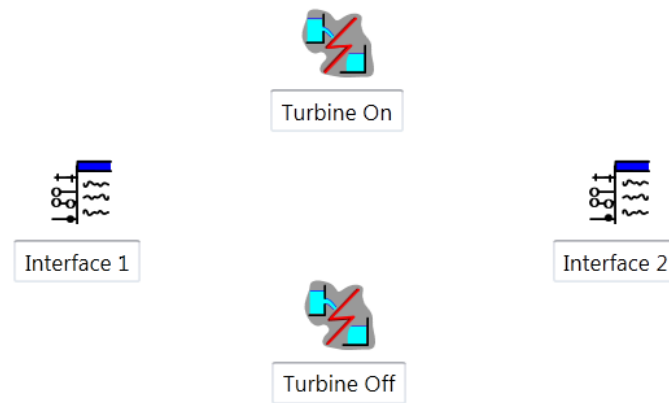


Figure 30 Objects creation in the *Regulation interface*

- Open the "Turbine On" *State* object with a right-click. The empty *State interface* is opened.
- Add two *Group Interfaces* and the desired combination of objects. For this example, add a *TurbineDB* (Figure 31).

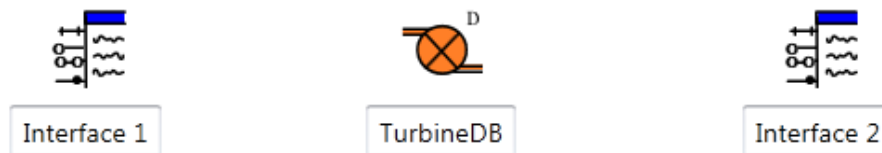


Figure 31 Objects creation in the "Turbine On" *State interface*

- In the Data Source frame (Figure 23), select for the line TurbineDB the Group and DataSet corresponding to the sensor created in the database.
- Double-click on the TurbineDB object to open the TurbineDB frame (right-side). Then, click on the Select station from Database button and define the corresponding station in the Station drop-down list. The link between the TurbineDB object and the database is now operational.
- Interconnections between the *TurbineDB* and both *Group Interfaces* have now to be added. One of them will ensure the connection from upstream objects, the second one to downstream ones.
 - For the *Interface 1*, connect it to the *TurbineDB* (water flow direction, as shown in Figure 32). In the *Variable selection* pop-up, select the link from the *TurbineDB* to the *Group Interface* (information direction).
As the water flow from *Reservoir* is defined by the *TurbineDB*, the information is transferred in the upstream direction from the *TurbineDB* to the *Reservoir* through the *Group Interface*.
 - For the *Interface 2*, link the *TurbineDB* to the *Group Interface*. In the *Variable selection* pop-up, the link from the *TurbineDB* to the *Group Interface* is preselected. Create the link with *Ok*.
In that case, both information and water flow are in the downstream direction (from the *TurbineDB* to the *Group Interface*).

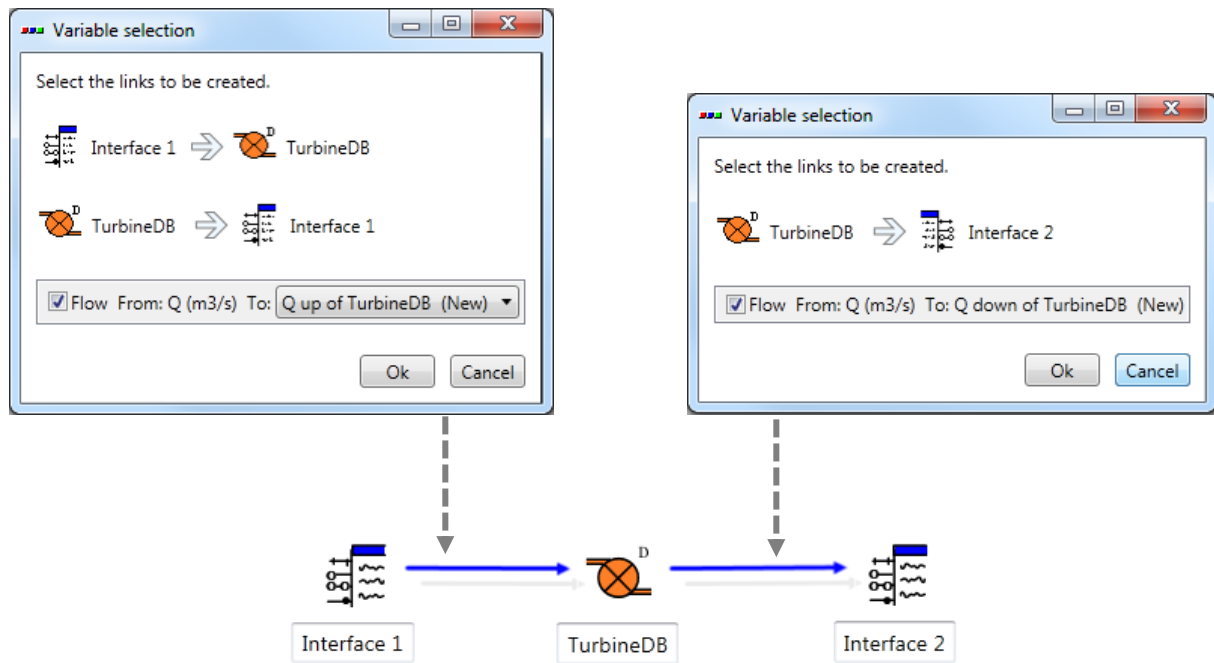


Figure 32 Links creation between the *TurbineDB* and the *Group Interfaces*

- Return to the upper hierarchical level (*Regulation Interface*) with the *Back* button (in the *Model* frame) or press the *Esc* button.
- Open the second *State* object ("Turbine Off") with a right-click. An empty *State interface* is opened.
- Add two *Group Interfaces*, and a *Turbine* with a *Time Series*. Interconnect the *Time Series* to the *Turbine* (Figure 33).

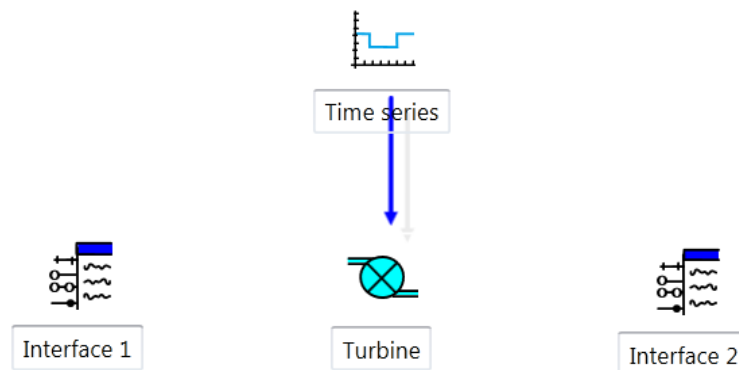


Figure 33 Objects creation in the "Turbine Off" *State interface*

- Double-click on the *Time Series*. In the *Series* frame, click on *Serie* and open the *Values* tab. Enter a series of data with time [seconds, starting from 0] and *QWanted* [m^3/s] as presented in Figure 34. ^{20 21}

²⁰ *Time series* are entered with time in seconds. The second 0 corresponds to the start time of the simulation. Consequently, a *Time series* can be used for different periods of simulation.

²¹ If the *Times series* does not completely cover the period of simulation, the last value of the series is constantly applied for the uncovered part. If the series varies with time, complete coverage of and adequate correspondence with the period of simulation has to be ensured.

Series	
Serie	
Graphs	Values
Time (s)	QWanted (m3/s)
0	0
10	0

Figure 34 Time series data for the “Turbine off”

- Interconnections between the Turbine and both Group Interfaces have now to be added, as shown in Figure 35. One of them will ensure the connection from upstream objects, the second one to downstream ones.

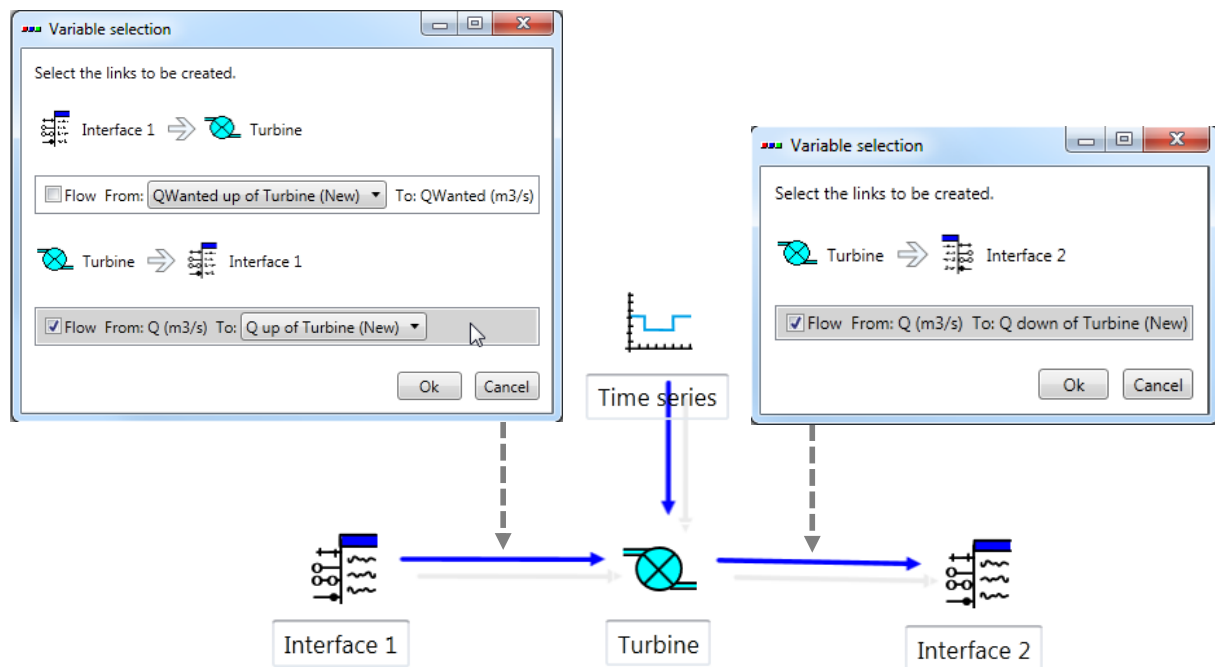


Figure 35 Links creation between the *Turbine* and the *Group Interfaces*

- Return to the upper hierarchical level (*Regulation Interface*) with the *Back* button (*Model* frame) or press the *Esc* button.
- Switch to *Connections* using the *space* key. Links between *Group Interfaces* and *States* will now be created. Similarly to the logic in the *State* objects, one *Group Interface* ensures the information exchange with upstream objects, the other one with the downstream ones.
For the first *Group Interface*, the one connecting the regulation with the upstream part of the model (*Interface 1* in Figure 36), connect it to the first *State* (arrow in water flow direction). The link to be created transfers the information (the *TurbineDB* flow) from *State* to the *Group Interface*.
- Connect the same *Group Interface* to the second *State*. Ensure that the name in the drop-down list in the *Variable selection* pop-up is the same as for the first *State* (without the indication "(New)" as the target of the link *Q up of TurbineDB 4* already exists).

Both *States* sending to the same reference in the *Group Interface*, only one variable will be available in the higher hierarchical level. As one and only one *State* can be active in a *Regulation*, this variable will always have one and only one value in the *Regulation* object.

- Both *States* are then connected to the second *Group Interface* (Figure 36). Again, both *States* point to the same link target (*Q down of TurbineDB* in the example) in the output *Group Interface*, this is why the first *State* to be connected will have the indication “(New)” in the dropdown menu and the second not.

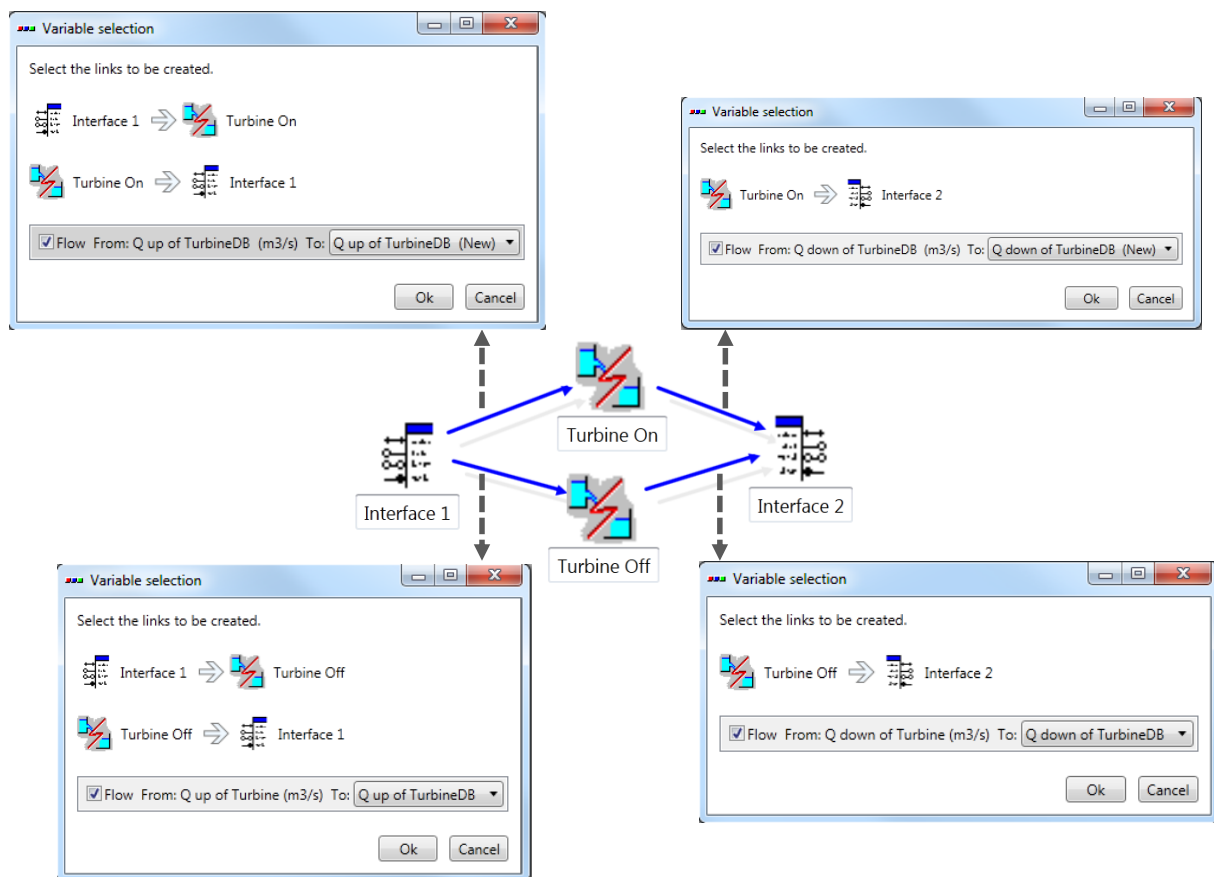


Figure 36 Links creation in the Regulation interface

- One more important operation in the *Regulation* is the definition of the *States transfer rules*. To do so, click on *Transitions* in the *Editing tools* frame or use *Ctrl+space* keys. The *State transfer mode* is entered: previously created links are hidden and only both *States* are visible.
- Link with *Transition arrows* the two *States*, as illustrated in Figure 37.



Figure 37 Transition links creation between *States*

Transitions rules are defined in each *Transition arrow* based on threshold values monitored by the *Sensor* objects. Table 5 presents the *Operators* used to define these automatic rules. Adequate use of the "...and" and "...or" functions allow the definition of combined rules.

Table 5 Operators used for automatic rules definition

Operator	Definition
$\geq$ than	Bigger than or equal to
$<$ than	Smaller than
and $\geq$ than	...and "bigger than or equal to"
and $<$ than	...and "smaller than"
or $\geq$ than	...or "bigger than or equal to"
or $<$ than	...or "smaller than"

- Using the operators presented in Table 5 and the threshold values defined in the *Sensor* used to monitor the *Reservoir* (see Figure 29), define transfer rules by clicking on the *Transitions arrows* and filling the cells in the *Transition* frame. Figure 38 provides an example of simple rules to switch between *Turbine On* and *Turbine Off*.

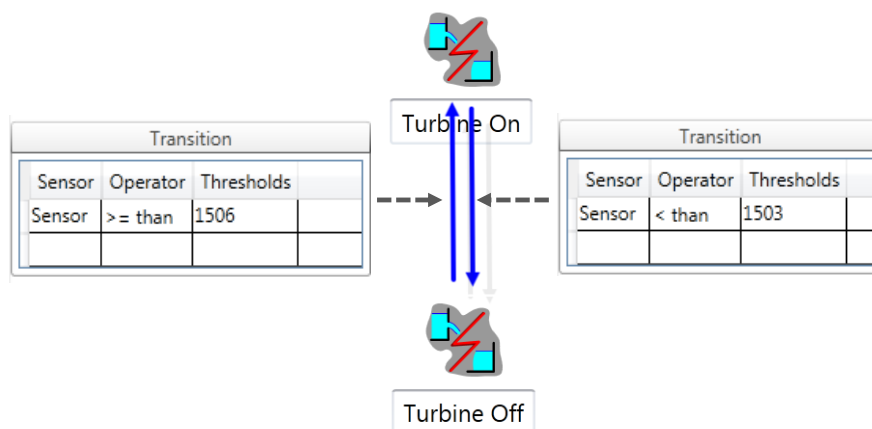


Figure 38 Example of transition rules in a *Regulation*. In the example, if the water level reaches 1506 [masl], the State *Turbine On* will be active as long as the level exceeds 1503 [masl]. If the level goes below 1503 [masl], the State *Turbine Off* will then be activated as long as 1506 [masl] is not exceeded in the reservoir, and so on.

Before exiting the *Regulation*, the *Initial state* has to be defined in the *Regulation* frame (right). In the drop-down list, select the *State* to be active at the beginning of the simulation.

- Return to the upper hierarchical level (*complete model*) with the  *Back* button (*Model* frame) or press the *Esc* button.
- Link the *Reservoir* to the *Regulation* and the *Regulation* to the *Junction* (see Figure 39).

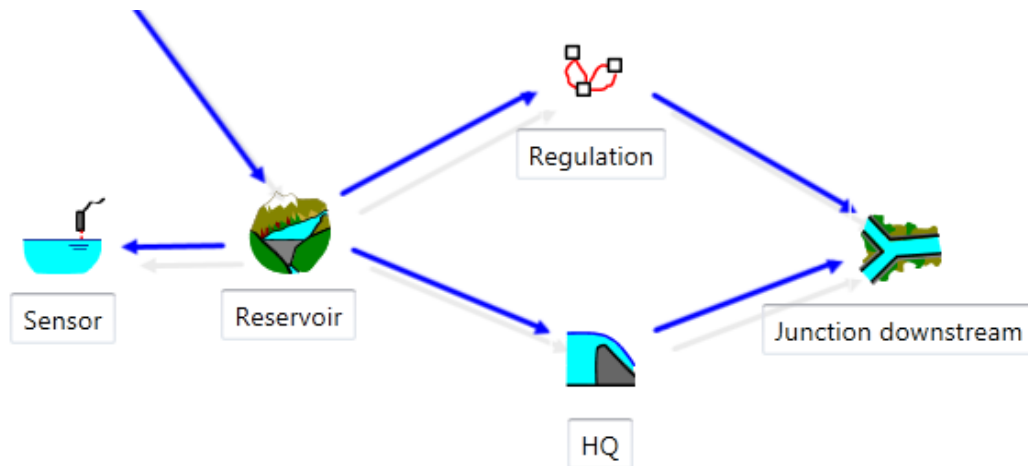


Figure 39 Connection of the *Regulation* with the upstream *Reservoir* and the downstream *Junction*

The *Regulation* object is ready for use.

Simulation with the regulation implemented

Once the two objects (*HQ* and *Regulation*) are implemented, validate the model and start the simulation. Results can be visualized by double-clicking on each object or by using the *Selection and Plots*.

Chapter 7: RS Expert

In this chapter, the four RS Expert modules are presented:

- Automatic calibration of hydrological model parameters;
- Stochastic simulation
- Time-slices simulation;
- Scenario simulation.

7.1 Automatic calibration

The complexity of a hydrological model calibration increases with the number of parameters to calibrate. The search for optimal values of calibration parameters can be made manually to a reasonable number of parameters. But in general, for large basins including hundreds or thousands of parameters, it is essential to have an automatic calibration tool.

In RS MINERVE, an automatic calibration can be realized in the *Hydrological calibration* tool (Figure 40).

- Click on *RS Expert* in the *Toolbox* frame (
- [Figure 1](#)). The *RS Expert* is opened (Figure 40). By default, the *Hydrological calibration* interface is showed.

Note that when *RS Expert* is opened, *RS MINERVE* is not active. Close *RS Expert* to use again *RS MINERVE*.

Calibration configuration

Different types of calibration can be achieved for an optimization:

- Regular calibration: One or more zones with a unique downstream gauged station, calibrated with the same parameters for all zones.
- Calibration per zone: One or more zones with a unique downstream gauged station, calibrated with different parameters per zones.
- Regional calibration: One or more zones with several downstream gauged station, calibrated with the same parameters for all zones.

The creation of a new calibration configuration can be realized following next steps (corresponding to the black boxes in the Figure 40):

- In the *Selection* frame (Figure 40), select the object types to calibrate: press simultaneously *Ctrl* on keyboard and left click on the object types. Then define the corresponding zone(s) by clicking on the *Zone Id* number(s).
All the objects corresponding to the selected object types and zone(s) appear in the *Models* frame (Figure 40). The correspondent parameters are shown in the *Parameters* frame (Figure 40).
- In the *Parameters* frame (Figure 40), select the parameters to calibrate. For each of them, define their minimum and maximum possible values (*Min* and *Max* columns)

and the value to be used for the first iteration of the calibration (*From model*, *Defined value* or *Random value*).

- If more than one zone has been selected (*Selection* frame), a column *Values per zone* appears in the table. For the parameter(s) selected for calibration, a box appears in this column. If the box is checked, the calibration for the parameter will consider a different value for each zone. If not, the same value will be considered for all zones in the concerned calibration.

Parameters can be imported in the model by clicking on  **Import P** in the *Parameters import/export* frame (Figure 40).

In the *Comparators* frame (Figure 40), select the comparator(s) whose the observed discharges will be used for the calibration (press simultaneously *Ctrl* on keyboard and left click on the comparators name to select more than one). If more than one comparator is selected, all will be taken into account in the objective function with the same weight.

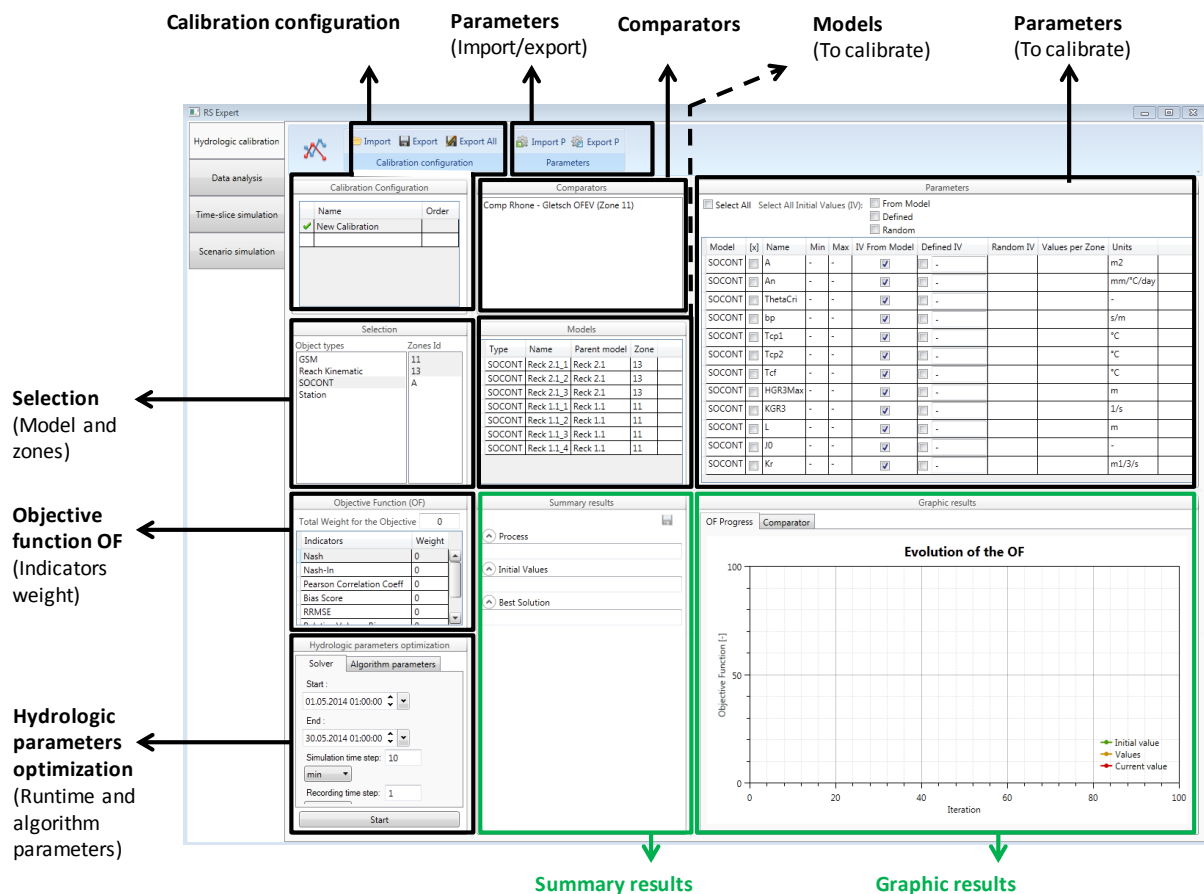


Figure 40 Interface of the Hydrological calibration module (in black: configuration; in green: results)

- Define the weight of each indicator to determine the objective function in the *Objective Functions* (OF) frame. Its total weight appears in the cell at the top of the frame.
- In the *Solver* tab of the *Hydrologic parameters optimization* frame (Figure 40), specify the calibration period and both *Simulation* and *Recording* time steps (Figure 41).

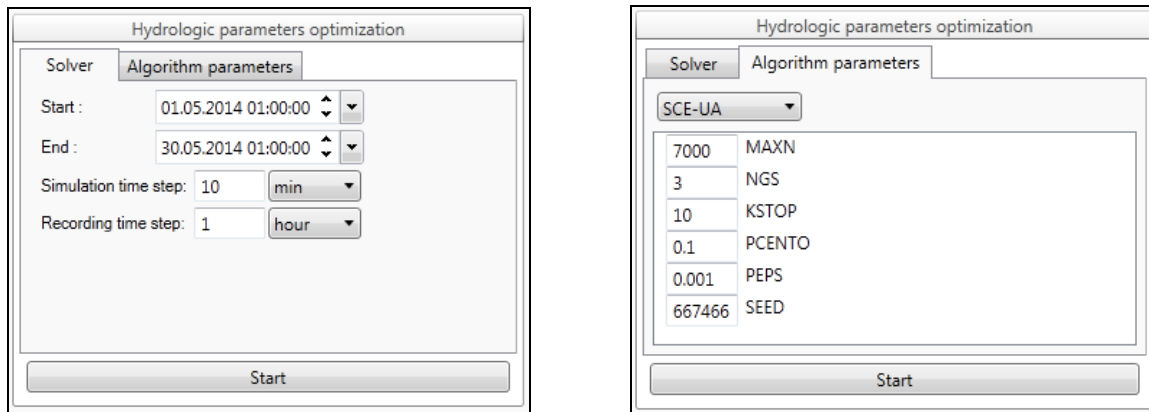


Figure 41 Calibration solver: both runtime (left) and algorithm properties (right)

In the *Algorithm parameters* tab of this same frame, define the algorithm type (SCE-UA in the example of Figure 41) and the corresponding parameters.

Three different algorithms (Shuffled Complex Evolution – University of Arizona - SCE-UA and Uniform Adaptive Monte Carlo - UAMC and Coupled Latin Hypercube and Rosenbrock - CLHR) are available in the actual version. For more information, see RS MINERVE – Technical Manual (García Hernández et al., 2015).

The mouse fly above of each parameter name shows their description.

- Click on  **Export** in the *Calibration Configuration* frame (Figure 40) to save the current calibration configuration. The produced file can be imported for the next calibration test.

To import an existing configuration, click on  **Import** in the *Calibration Configuration* frame (Figure 40) and load the file.

Calibration start/stop

- Click on  in the *Hydrologic parameters optimization* frame to launch the calibration.
If the calibration configuration is valid, a « Start » message with the current date appears in the *Process* tab in the *Summary Results* frame. Otherwise, a red error message is displayed at the bottom of the *Solver* tab and describes the problem to resolve.
- Click on  in the *Hydrologic parameters optimization* frame to stop the calibration. It takes a moment to stop until the current simulation ends.

Calibration results

After each simulation during the calibration, the following results are showed in the *Summary Results* frame (Figure 40 and Figure 42):

- The Objective Function (OF), with its maximum possible value.
- The results of the simulation before optimization with initial parameters, initial indicators values and initial OF value.
- The results of the current iteration with its parameters values and the respective indicators values and OF value.
- The best result, with related parameters and OF value.

These results can be exported at all times by saving with the Save button located in the same frame or by copying then pasting the text in a file.

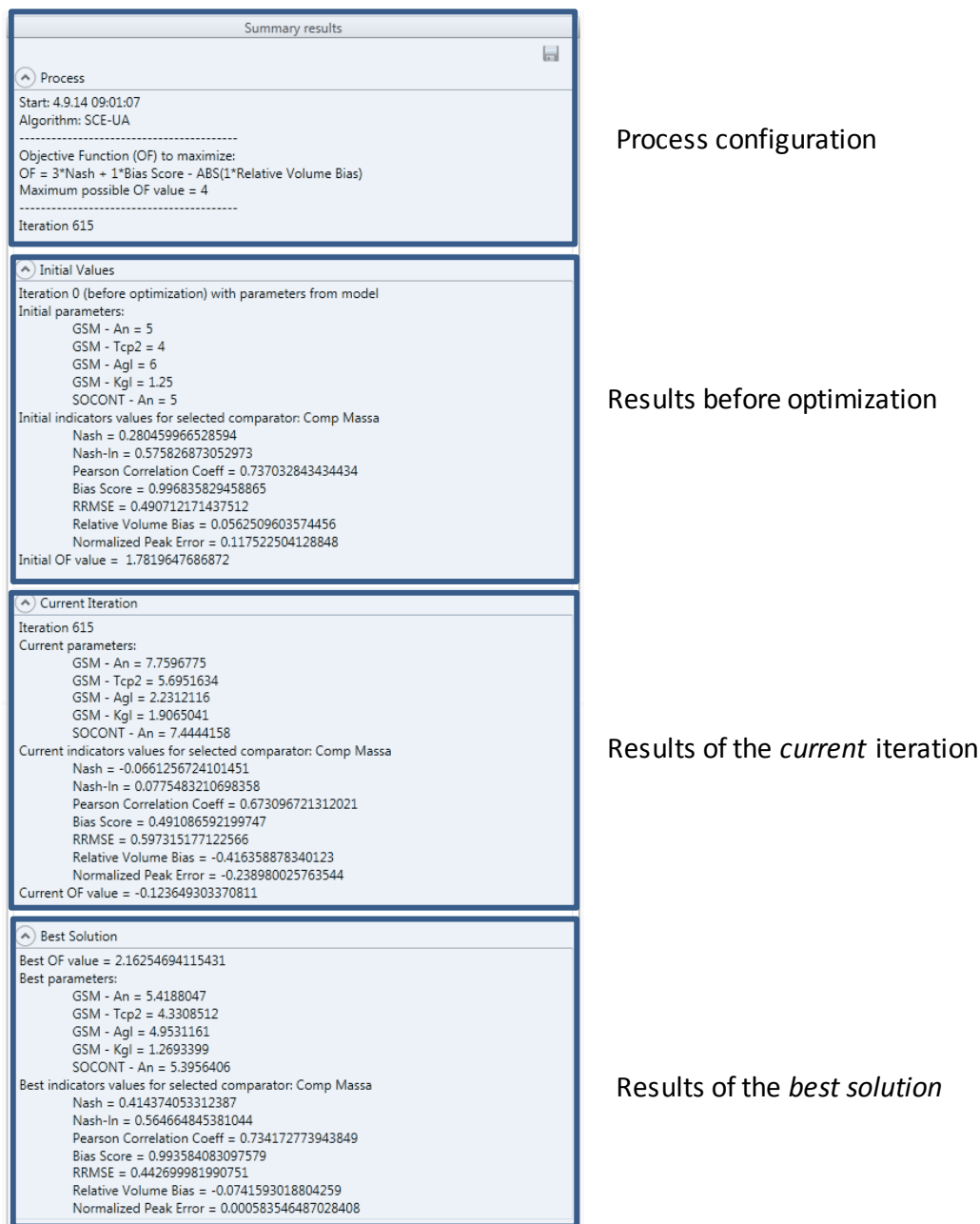


Figure 42 Textual results of the calibration in progress

If more than one comparator has been selected in the *Comparators* frame, the Objective Function is equal to the sum of the objective functions obtained at each compactor.

The results of the calibration in progress can also be visualized as graphic form in the *Graphic Results* frame (Figure 40 and Figure 43):

- The *OF Progress* tab shows the temporal evolution of the Objective Function (OF), with Initial value in green, current value in red and all other values in orange. The activation of the mouse wheel on vertical axis allows to zoom on the OF values of interest.
- The *Comparator* tab allows following the progression of the current simulated hydrograph with respect to the observed one. If more than one comparator had been

selected for the calibration in the *Comparators* frame, the comparator to show can be modified by clicking on the one of interest in the same frame.

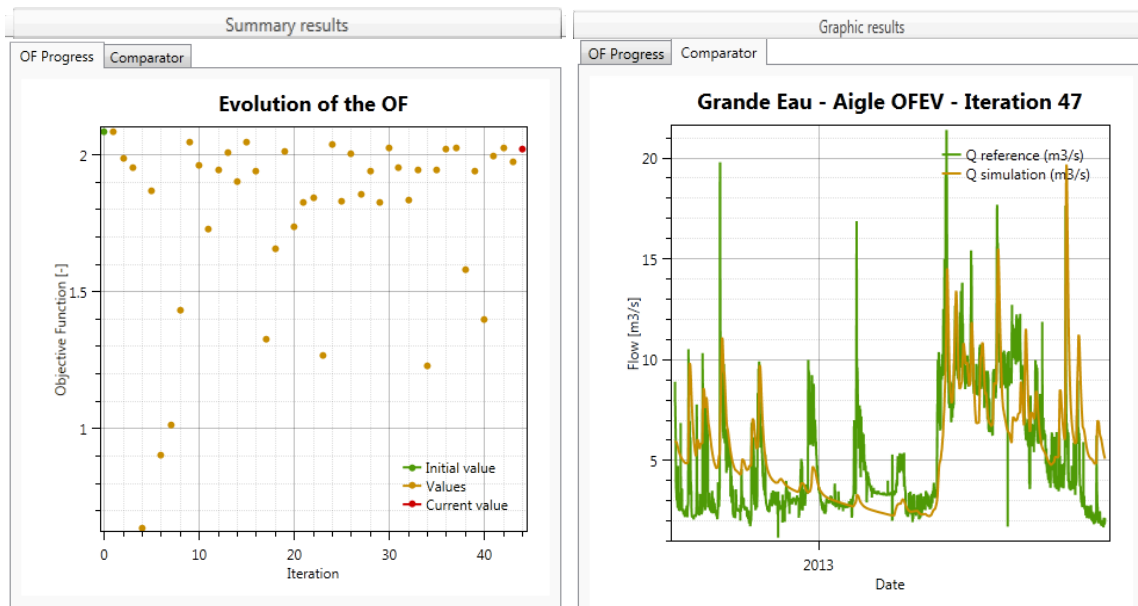


Figure 43 Graphic results of the calibration in progress. Evolution of the Objective function (left) and hydrograph of both observed and current simulated discharge (right).

At the end of the calibration:

- The parameters obtained for the best *Objective Function* value are applied in the current model. If the model is saved, the parameters are stored; if not, the hydrological model keeps the initial parameter values.
- The parameters can be also exported in a file by clicking on  **Export P** in the *Parameters import/export* frame (Figure 40).

Multiple calibration

Additionally, in combination with all possible optimizations, multiple calibrations can be achieved:

- Unconnected basins calibration: several independent basins can be calibrated if the same “order” is provided for all of them.
- Upstream-downstream basins calibration: Different dependent basins can be calibrated from upstream to downstream (“order” grows up from upstream to downstream).

Parallel and series calibration can be combined for a complex basin as presented in example of the Figure 44, where two unconnected basins are calibrated in Calibration A and Calibration B, then a downstream basin is calibrated in Calibration C and, finally, a more downstream basin is calibrated in Calibration D.

Calibration Configuration		
	Name	Order
✓	Calibration A	1
	Calibration B	1
	Calibration C	2
	Calibration D	3

Figure 44 Example of a calibration with two unconnected basins and two basins upstream

7.2 Stochastic simulation

This new module is capable of generating a set of simulations based on different parameters or initial conditions with values located in a random interval defined by the user. For each element of the model, simulated hydrographs, corresponding statistics (mean, median, quartiles, minimum and maximum values), and related set of parameters for each simulation are provided. The probability distribution in the random interval is uniform.

7.3 Time-slice simulation

The computation duration logically increases with the model complexity but also with the simulation period length. Thus, simulations on long periods with short time steps and a complex model can become inappropriate for user's computer performance. In this case, it is necessary to clip the simulation period in time-slices.

In RS MINERVE, a time-slice simulation can be realized in the *Time-slice simulation* tool.

- Click on *RS Expert* in the *Toolbox* frame (
- Figure 1). The *RS Expert* is opened. Then click on *Time-slice simulation* in the top left part of the windows (Figure 45).



Figure 45 Interface of the Time-slice simulation module (in black: configuration; in green: results)

Note that when *RS Expert* is opened, *RS MINERVE* is not active. Close *RS Expert* to use again *RS MINERVE*.

Time-slice configuration

The creation of a new time-slice configuration can be achieved following next steps (corresponding to the black boxes in the Figure 45):

- In the *Inputs* frame (Figure 45), select the dataset(s) for each data source (Station, TurbineDB, Source, etc...). For example, for the *Data Source* of *Station* objects: click on *Station*, search the corresponding dataset name(s) and check it.

More than one dataset can be checked for each type of input. If a period of the simulation is covered by more than one dataset, the dataset starting first is used

- In the *Selection* frame (Figure 45), choose the *model selection* to be used.
- Then, select the object's series to be displayed.

The *model selection* is also used for the results exportation.

- In the *Outputs* frame (Figure 45), define the outputs to be recorded: *All results* (all the simulation results of the model) and/or *Results from selection* (which considers only the above selected model selection). For each one, it is possible to record:
 - *Each simulation*: one dataset will be produced by time-slice (see *Simulation period* in *Solver* frame at Figure 45);
 - *Combined simulations*: only one dataset will be produced for all the period;
 - *Nothing*: no dataset will be produced;
- In the *Solver* frame (Figure 45), specify:

- The entire simulation period: *Start and End dates.*

By default, the maximum possible period to be simulated is proposed. It corresponds to the maximum period covered by the datasets in each object type for which at least one dataset is selected. Manual modification can only shrink the extent of the simulation period.

- The time-slice or *Simulation period: annually, monthly, etc...;*
- Both *Simulation and Recording time steps.*

Time-slice simulation start/stop

- Click on  in the *Solver* frame to launch the time-slice simulation.

If the model is valid, the simulation starts. In addition, success of each time-slice is presented with a green progress bar (Figure 46, left). If one time-slice cannot be achieved, the RS MINERVE error window is displayed and a gray progress bar is shown (Figure 46, right).

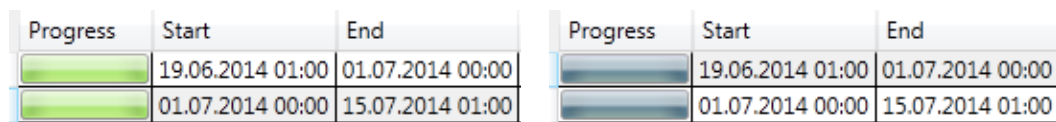
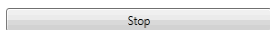


Figure 46 Progress state after success (left) and failure (right) of the simulation

- Click on  in the *Solver* frame if necessary to stop the simulation. All results until that moment are saved

Time-slice results

After each computation of each time-slice, next components are showed:

- In the *Solver* frame, the progress bar of each time-slice;
- In the *Selection* frame, the series of the components selected in the object list for the last computed time-slice.
- In the Comparators frame: the values of the indicators checked under *Indicators to visualize* for the selected comparators are graphically shown in the top part of the frame and in tabular form in the bottom part of the same frame (Figure 47).

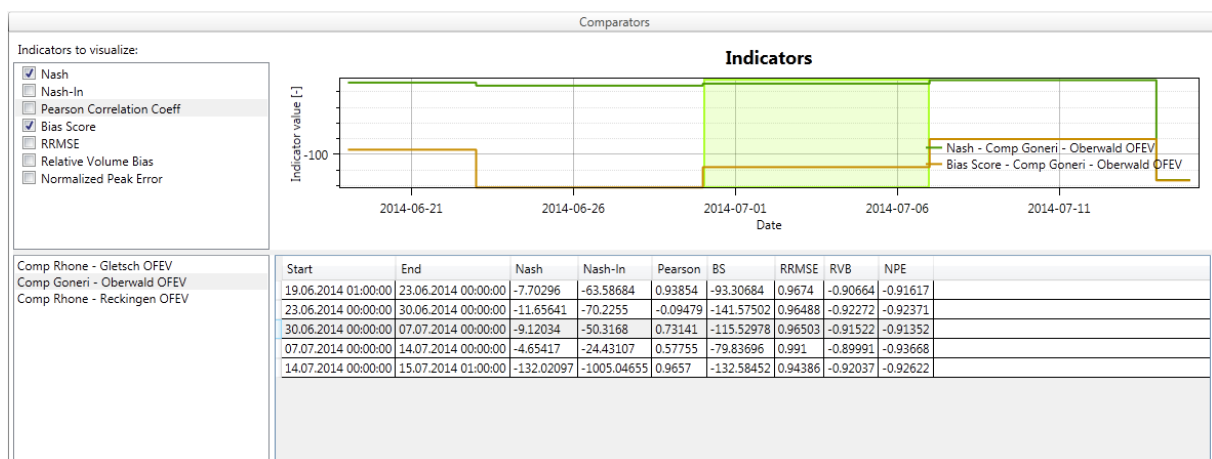


Figure 47 Visualization of indicators at the different comparators

Objects selection in the *Selection* frame as well as indicators and comparators to consider in the *Comparators* frame can be modified during the Time-slice simulation.

The tabular results of indicators can be exported at any time by copying them and pasting the text in a file.

At the end of the time-slice simulation, the outputs datasets are available in the same repository than those of the database.

7.4 Scenario simulation

To evaluate the model sensitivity (i.e. the simulated flows) to the Initial Conditions, to the parameters and also to the meteorological inputs, it is necessary to run a lot of simulations to test different sets of values. But for the user it is very tedious to launch these many scenarios simulations.

In RS MINERVE, scenario's simulations can be realized in the *Scenario simulation* tool.

- Click on *RS Expert* in the *Toolbox* frame (
 - Figure 1). The *RS Expert* is opened.
- Then click on the *Scenario simulation* in the top left part of the windows (Figure 48).

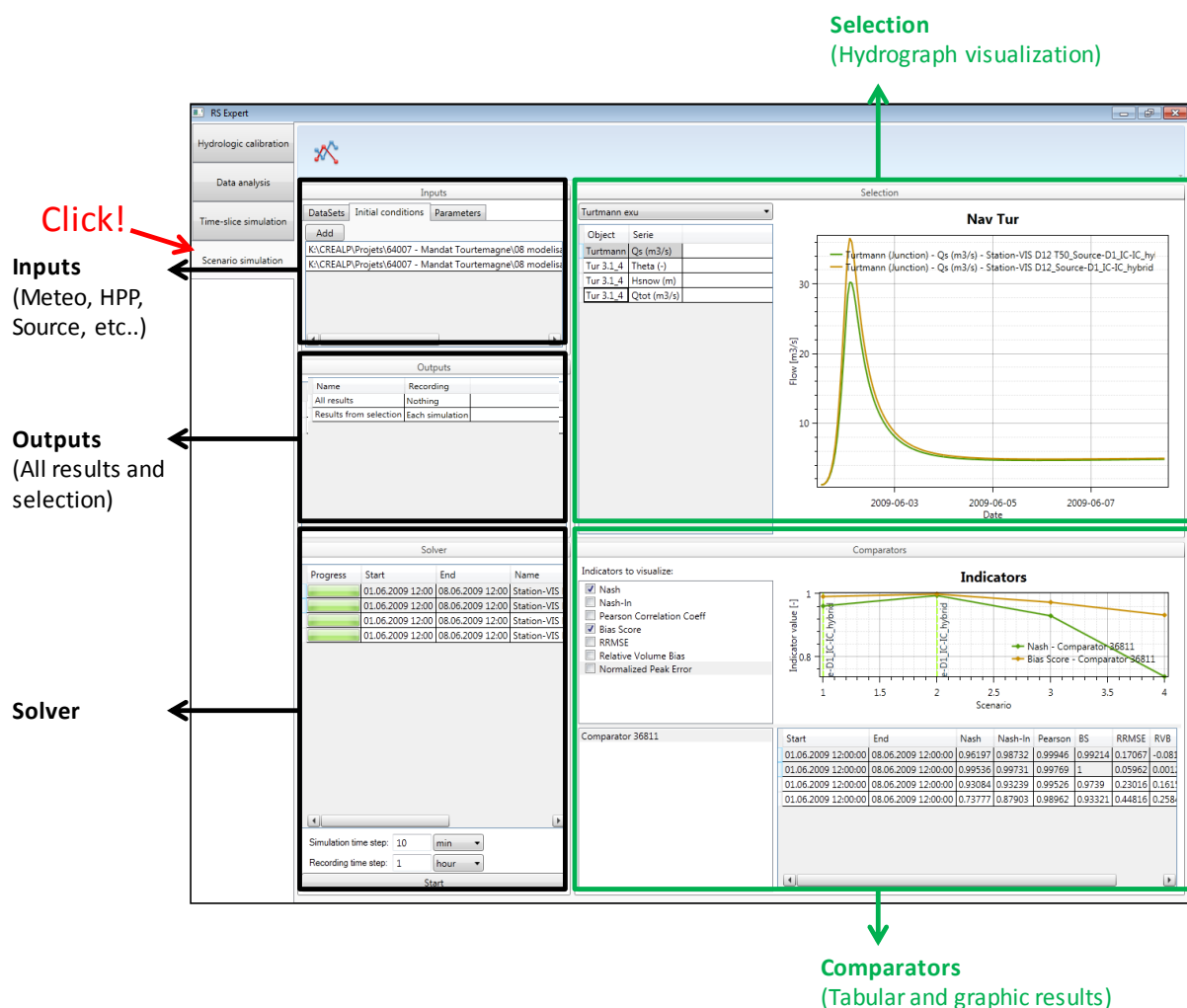


Figure 48 Interface of the Scenario simulation module (in black: configuration; in green: results)

Note that when *RS Expert* is opened, *RS MINERVE* is not active. Close *RS Expert* to use again *RS MINERVE*.

Scenarios configuration

A scenario is composed of a combination of input datasets (one for each type of *Input data*), a set of initial conditions and a set of parameters. Except the dataset for the *Station* input (meteorological inputs) when the model contains at least one *Virtual weather station*, all other inputs are optional. Initial conditions and parameters can be provided as text or worksheet files.

All possible combinations composed of every input type with at least one dataset or input file are proposed, but the user can erase undesired simulations.

The creation of a new scenarios configuration can be achieved following next steps (corresponding to the black boxes in the Figure 45):

- In the *Inputs* frame (Figure 48), click on the *DataSets* tab (Figure 49). Select the dataset(s) to be used as data sources for the different *Inputs*: *Station*, *TurbineDB*, *Source*, *Reservoir* and *Consumer* (only object types existing in the model are listed). For example, for the *Station* data source, click on *Station* in the left part, search the corresponding dataset name(s) in the right part and check it/them.

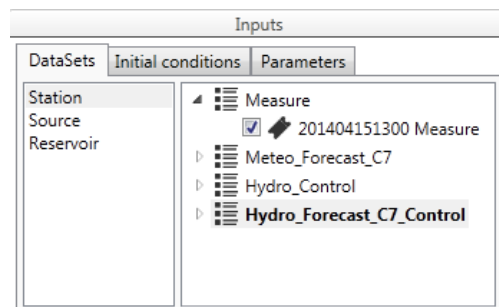


Figure 49 *Inputs* frame in the Scenario simulation tool

- Click on the *Initial conditions* tab (Figure 49). If you want to add initial conditions (IC) file(s), click on and import the desired IC files. The selected ones are listed in the *Inputs* frame.
- Click on the *Parameters* tab (Figure 49). If you want to add parameters file(s), click on and import the desired parameters files. The selected ones are listed in the *Inputs* frame.
- In the *Selection* frame (Figure 48), choose the *model selection* to be used.
- Then, select the object's series to be displayed.

The *model selection* is also used for the results exportation.

- In the *Outputs* frame (Figure 48), define the outputs to be recorded: *All results* (all the simulation results of the model) and/or *Results from selection* (which considers only the above selected model selection). For each one, it is possible to record:
 - *Each simulation*: one dataset will be produced by time-slice (see *Simulation period* in *Solver frame* at Figure 48);
 - *Combined simulations*: only one dataset will be produced for all the period;
 - *Nothing*: no dataset will be produced;
- In the *Solver* frame (Figure 48), specify:
 - Both *Simulation* and *Recording* time steps;

The period of each scenario simulation will only correspond to the period covered by all the datasets composing the scenario. If the covered periods for a scenario do not overlap for more than one time step, a gray progress bar is displayed (since simulation cannot be achieved).

The name of the output file of each scenario is composed by merging the names of all the datasets used for the scenario. The input type of each dataset (e.g. Station, Source) is added before the name of each dataset (e.g. "Station-Datameteo_Source-Datasource...")

Scenario simulation start/stop

- Click on  in the *Solver* frame to launch the time-slice simulation.

If the model is valid, the simulation starts. Success of each scenario is presented with a green progress bar (Figure 50). If the current scenario is not valid, the RS MINERVE error window is displayed and a gray progress bar is shown (Figure 46, right).

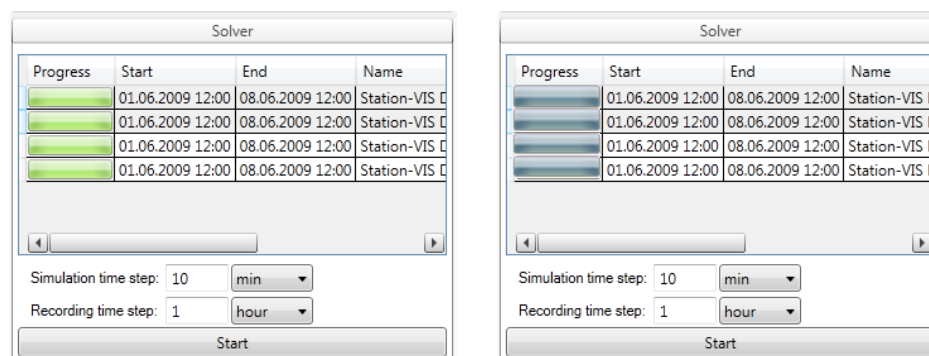


Figure 50 Progress state after success (left) and failure (right) of the simulation

- Click on  in the *Solver* frame if necessary to stop the simulation. All results until that moment are saved.

Scenarios results

After simulation of each scenario, following components are showed:

- In the *Selection* frame: the temporal evolution of the selected object's series;
- In the *Comparators* frame: the values of indicators checked at the top left of the frame (*Indicators to visualize*). These values are displayed as graphical and tabular forms and correspond to the comparator selected in the bottom left of the *Comparator* frame;

During the simulation, you can change all the objects or all indicators or all comparators to visualize by clicking on or checking them. The tabular results of indicators can be exported at all times by copying then pasting the text in a file.

At the end of the scenario simulation, the outputs datasets are available in the same repository than those of the database.

Chapter 8: RS GIS

The RS GIS module allows the user to manage and process geospatial data. In this chapter, the RS GIS interface and its different tools are presented.

8.1 RS GIS interface

To start RS GIS:

- Click on *RS GIS* in the *Toolbox* frame (
- Figure 1). The *RS GIS* is opened (Figure 51).

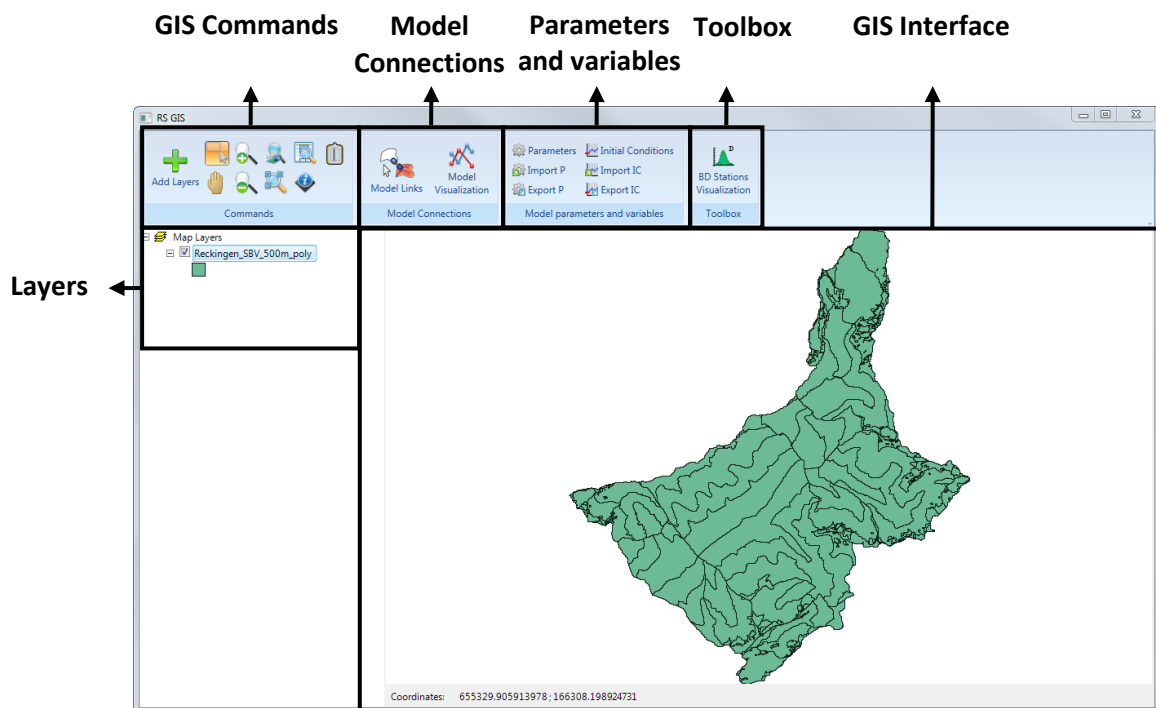


Figure 51 Interface of the RS GIS

8.2 GIS Commands

Importation of new layers

To add geospatial data in the GIS Interface,

- Click on the *Add layers* button in the GIS Commands window (Figure 51).
- Move up/down the different layers and use the check boxes to display or not the layers.

! The file path of the shapefile is added to the hydrological model (.rsm) , not the whole shapefile.

Tools for interaction in the interface



Select features by rectangle



Pan



Zoom in



Zoom out



Zoom to layer extent



Zoom to global extent



View attribute table of selected layer



View information on selected feature



Copy values from clipboard

8.3 Model Links

The *Model Links* tools in the *Model Connections* frame simplify the creation of hydrological models and allow the visualization of the state variables and parameter's values in the GIS interface. It is possible to use *Model Links* only after a layer has been added to the GIS. Once you have added a layer to the interface,

- Select the layer on the left side of the interface window.
- Click *Model Links* in the *Model Connections* frame.

An attribute table (for the selected entities) as well as an action area with three tabs should appear below the GIS interface (Figure 52)

- Select features of the selected layer in order to bring them up in the attribute table (use the *Select All* button to select all features).
- In the action area, select in the drop-down menu a Field Name (layer attribute) that should be used to identify features.

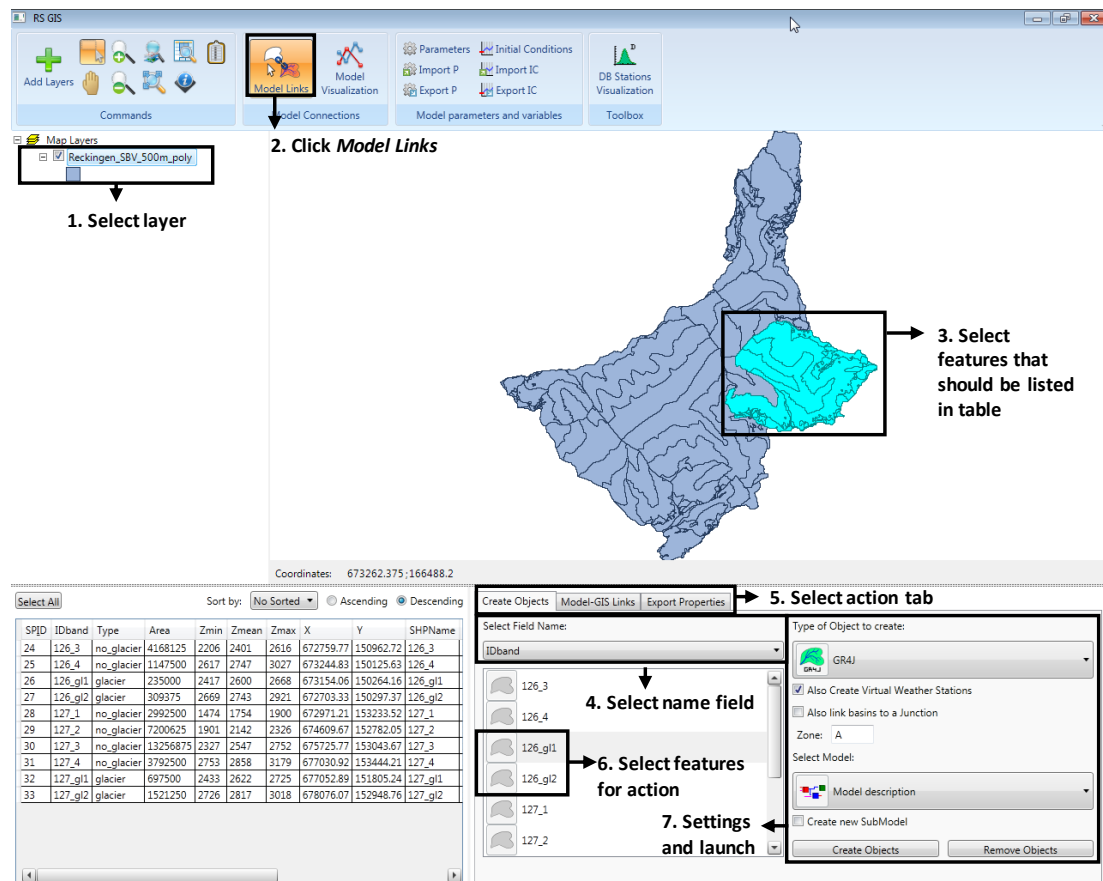


Figure 52 Model Links interface in the GIS and its workflow

The three tabs offer you the possibility of the following actions:

- **Create Objects:** Create model objects from GIS features.
- **Model-GIS Links:** Link GIS features to existing model objects.
- **Export Properties:** Export feature properties to properties (parameters) of model objects.

Create Objects

In the following example, we are going to generate a sub-model of the subcatchment highlighted in blue in Figure 52, which has both normal and glacial elevation bands.

- Select the *Create Objects* action tab
- Select all non-glacial features by holding Ctrl while clicking (Step 3 in Figure 52). Using the sorting tool for the attribute table might help to order the objects.
- Under *Type of Object to create*, select a non-glacial basin model (like SOCONT).
- Put a check on *Also Create Virtual Weather Stations*. Now, a virtual weather station will be created for and linked to each created object.
- Put a check on *Also link basins to a Junction*. Now, all created objects will be linked to a single newly created junction.
- Under *Select Model*, select the model in which you wish to place the newly created objects. In our case, this is the parent model.
- Put a check on *Create new Submodel* and give it a name. Now, a submodel will be created and contain all the newly created objects.
- Click *Create Objects*.

Once the creation process is finished, a message is displayed and object icons are displayed next to each of the features, to indicate that the features and the objects have been linked (Figure 53).

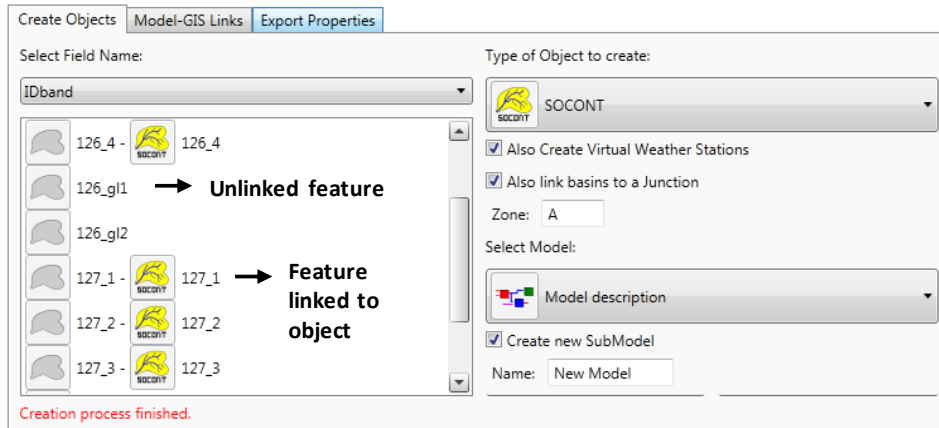


Figure 53 Object creation process completed

We then create the glacial objects:

- Select glacial features by holding Ctrl while clicking (Step 3 in Figure 52).
- Under *Type of Object to create*, select a glacial basin model (like GSM).
- Put a check on *Also Create Virtual Weather Stations*. Now, a virtual weather station will be created for and linked to each created object.
- Put a check on *Also link basins to a Junction*. Now, all created objects will be linked to another single newly created junction.
- Under *Select Model*, select the model in which you wish to place all newly created objects. In our case, this is the model that was previously created.
- Remove the check from *Create new Submodel*, since we created our submodel in the last step.
- Click *Create Objects*.

If we now view the hydraulic submodel that was created we see that all the SOCONT and GSM objects were created and linked to both a junction and a virtual station (Figure 54)

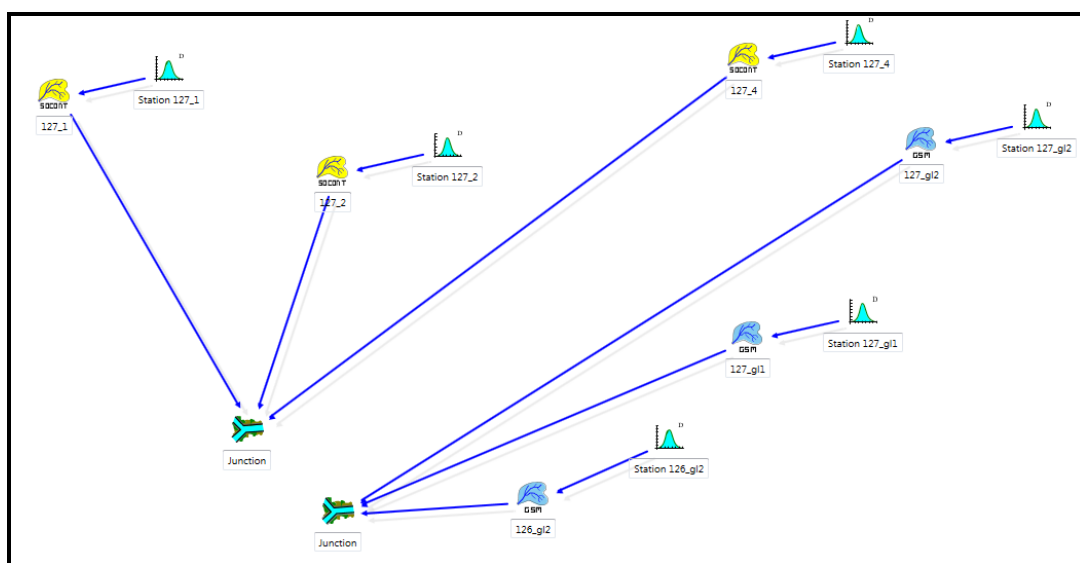


Figure 54 Automatically generated objects

It is still necessary to link the junctions to a group interface and define certain properties of the basins (area) and virtual stations (coordinates) in order for the submodel to be complete. In *Export Properties*, we see how these properties can be exported by bulk from the linked shapefile features.

Model-GIS Links

It is important that model objects be linked with GIS features for two reasons. First, it allows properties to be efficiently exported from the features to the object (see next section). Second, it allows model simulation results to be viewed in the GIS (See Figure 57).

In the following, we explain how to remove and create a link between a feature and an existing model object.

Link creation

To create a link,

- Select an unlinked feature in the link viewer.
- Select a model object in the right-hand list.
- Click the *link* icon situated below the *Auto-Link* button.

Link removal

To remove a link,

- Select the link you wish to remove in the link viewer on left side of Figure 55.
- Click the *unlink* icon situated below the *Auto-Link* button.

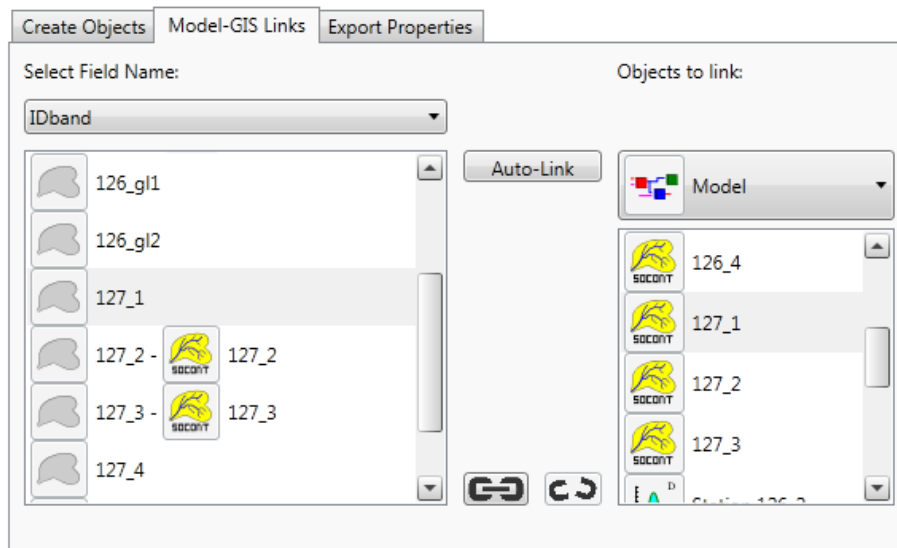


Figure 55 Linking and unlinking elements. Here, the two elements are ready to be linked.

Auto-linking objects

If the object names match the Field Name displayed in the link viewer, then you can use the *Auto-Link* button to match and link the elements automatically.

Export Properties

Properties can be exported from a linked feature directly to the basin model or to its associated virtual weather station. There are two properties that you will definitely want to export from the GIS to the hydraulic model: Basin area and the coordinates of the virtual weather station of each basin.

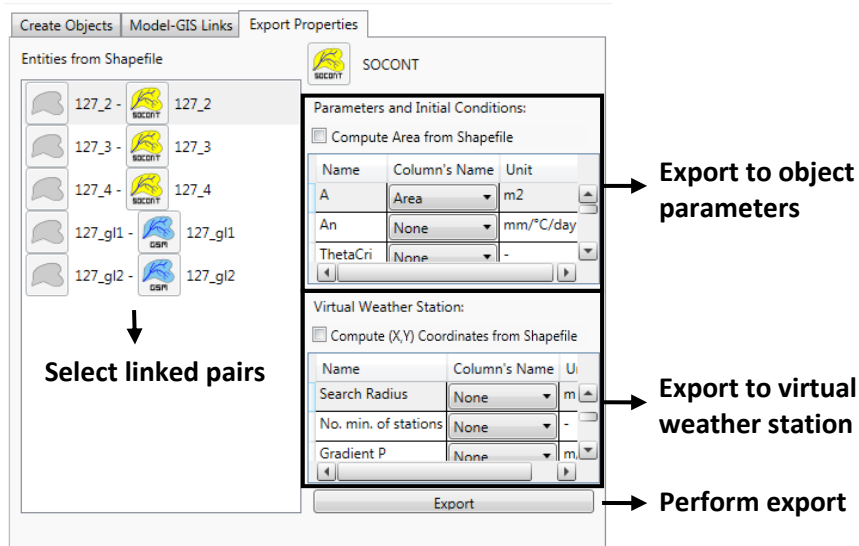


Figure 56 Exporting feature attributes to model objects

Export pre-calculated feature attributes

In order to use a feature attribute as a model parameter value,

- Select a linked pair of elements in the *Export Properties* tab.
- Navigate to the model parameter that you wish to change, and in the drop-down list, select the attribute of the linked feature that should be used.

Compute properties from the shapefile

The area of a basin, as well as average X and Y coordinates, can be calculated directly from the feature itself instead of using a pre-calculated feature attribute. In order to do that,

- Select a linked pair of elements in the *Export Properties* tab.
- To compute the area for the different sub-basins, select *Compute Area from Shapefile*.
- To compute the centre of gravity for the virtual weather station, select *Compute (X,Y) Coordinates from Shapefile*.

The action can be performed on multiple pairs at the same time, but only pairs of objects of the same type (i.e. only pairs of SOCONT objects). The action cannot be applied to different object types at the same time because different object types have different sets of parameters.

8.4 Hydro Model Visualization

The *Model Visualization* module lets you visualize and edit model information from within the GIS interface. There are three tabs for interaction:

- **Object Info:** view and edit model object parameters.
- **Solver:** run a simulation.
- **Spatial View:** Change the colours of GIS features based on values from linked objects.

! Shapefile features must be linked to a model object in order for information to be displayed.

Spatial View

The Spatial View (Figure 57) allows you to visualize either results, parameters, or initial conditions at each of the objects.

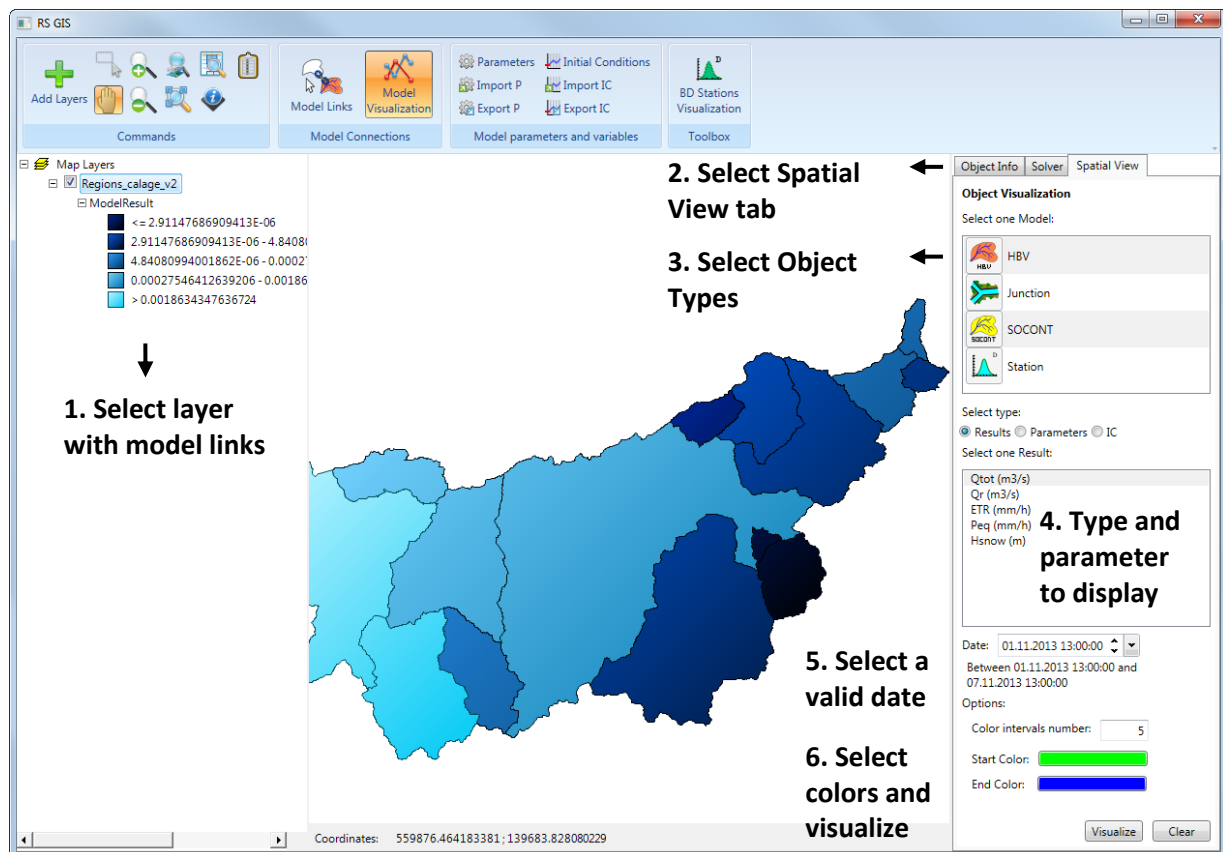


Figure 57 Hydro Model Visualization: interface workflow in the Spatial View

In order to perform a visualization,

- Select the layer that you wish to visualize. Features from this layer must be linked with model objects.
- Select the *Spatial View* tab.
- Select the object types that you wish to visualize. Multiple selections can be made, but different object types must share a parameter in order to be displayed.
- Select the parameter type from either *Results*, *Parameters*, or *Initial Conditions*.

- Select the parameter that you wish to display.
- If you are viewing simulation results, select the date for which results should be displayed.
- Optional: change color settings.
- Click on *Visualize*.

8.5 DB Stations Visualization

The *DB Stations Visualization* tool allows spatial representation of the stations contained in a database or a dataset.

The stations are represented directly in the RS GIS interface. The coordinates are taken from the X, Y and Z coordinates from the position of the stations.

Data requirements

The input is composed of a dataset or a database (RS MINERVE format).

Procedure

The steps to plot in RS GIS the stations' location are presented hereafter.

- In RS GIS, click on the *DB Stations Visualization* button (*Toolbox frame*).
- Select the dataset or the database to be considered.

A new layer of points is created and displayed in the GIS interface (Figure 58). The user can posteriorly save the layer.

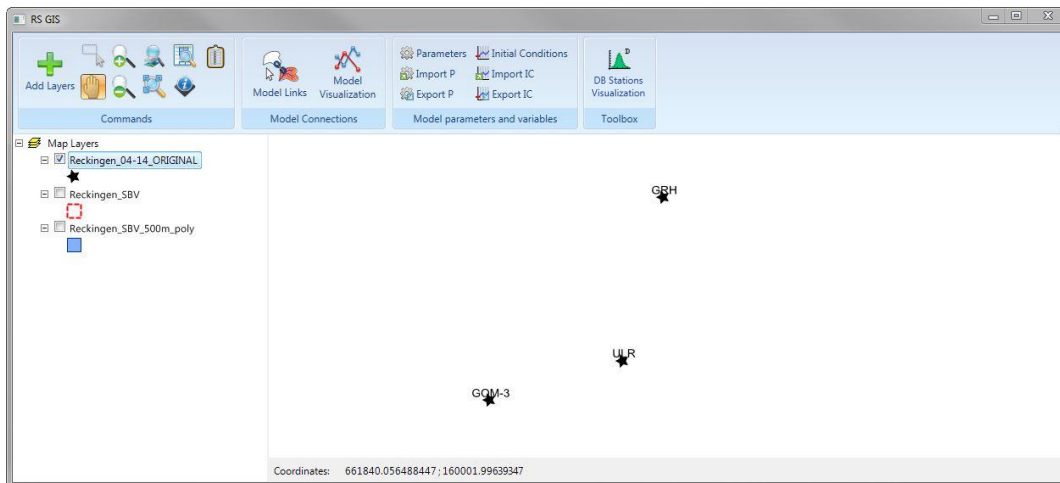


Figure 58 Visualization of stations' location in RS GIS

Chapter 9: Examples of application

In this chapter, some examples of application are presented in order to deepen the knowledge of the program. These basic examples are designated to facilitate the learning of the program RS MINERVE. The examples are organized according to the degree of difficulty.

The use of RS MINERVE in case studies has demonstrated the capacity of the program to correctly reproduce the real behavior of river basins. In addition, the program facilitates the search of different scenarios of operation while optimizing complex systems in a satisfactory way.

This chapter contains three examples with didactic aims:

- Example 1 – Simple basin with only runoff.
- Example 2 - Combined full basin with meteorological stations.
- Example 3 - Equipped basin with a hydropower scheme.
- Example 4 – Automatic calibration of a model

9.1 Example 1 – Simple basin with only runoff

In the first example the objective is to model the production of a net rain-flow of three impermeable basins, then the propagation of two hydrographs, the implementing of three inflows at a confluence and finally their propagation to the model outlet (Figure 59).

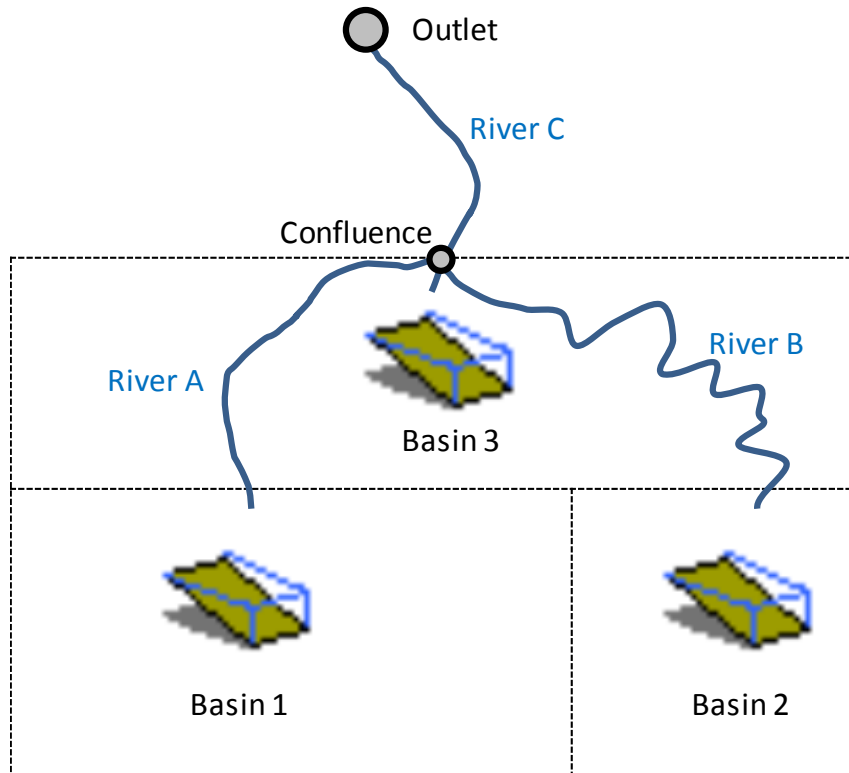


Figure 59 Model scheme

The three impermeable surfaces are supposed to be located in the same region, thus receiving an identical precipitation. Each surface has its own outlet into different rivers (A and B) which are joined later on in a single final river (C) before flowing into the outlet of the model. The parameters and the state variables of the three surfaces, of the three rivers and the precipitation data are provided in Table 6. The three rivers are modeled with the kinematic wave model.

Objective of Example 1

The requested result is the hydrograph at the model outlet during 24 hours, after the beginning of the precipitation, as well as the peak discharge and the peak time.

The simulation parameters are:

- Simulation time step = 600 s;
- Recording time step = 600 s.

A uniform and null ETP is assumed for this example (the user can check the selected ETP method in the RS MINERVE settings).

Table 6 Characteristics of the objects

Precipitation	
time (h)	rain (mm/h)
0	0
1	1.08
2	1.44
3	1.80
4	2.88
5	5.40
6	8.28
7	9.97
8	6.84
9	5.04
10	3.24
11	2.63
12	1.44
13	0.72
14	0

SWMM 1		
Parameters and initial conditions	Values	Units
A	1.00E+07	m ²
L	1500	m
JO	0.1	-
K	1.9	m ^{1/3} /s
Hini	0	m

SWMM 2		
Parameters and initial conditions	Values	Units
A	4.00E+06	m ²
L	3000	m
JO	0.05	-
K	1.5	m ^{1/3} /s
Hini	0	m

SWMM 3		
Parameters and initial conditions	Values	Units
A	8.00E+06	m ²
L	2500	m
JO	0.02	-
K	1.3	m ^{1/3} /s
Hini	0	m

River A		
Parameters and initial conditions	Values	Units
L	3000	m
BO	6	m
m	1	-
JO	0.001	-
K	30	m ^{1/3} /s
Qini	0	m ³ /s

River B		
Parameters and initial conditions	Values	Units
L	4000	m
BO	4	m
m	1	-
JO	0.005	-
K	30	m ^{1/3} /s
Qini	0	m ³ /s

River C		
Parameters and initial conditions	Values	Units
L	2000	m
BO	7	m
m	1	-
JO	0.001	-
K	30	m ^{1/3} /s
Qini	0	m ³ /s

Resolution of Example 1

This first example is a simplified representation of the reality. Despite of that, it allows the familiarization with the concept of *RS MINERVE* and to know more about its hydrological objects.

At first, the object “*Time Series*”  is introduced. Clicking once on its icon in the *Objects frame*, a pen appears. You can then click in the graphic interface for creating the object in the position you want. Next, the three run-off surfaces are created by means of the object “*SWMM*” . The three rivers are introduced by selecting the model “*Reach Kinematic*” . The model built-up will be finished with the introduction of the two objects “*Junction*” . The graphical interface at this stage is presented in Figure 60.

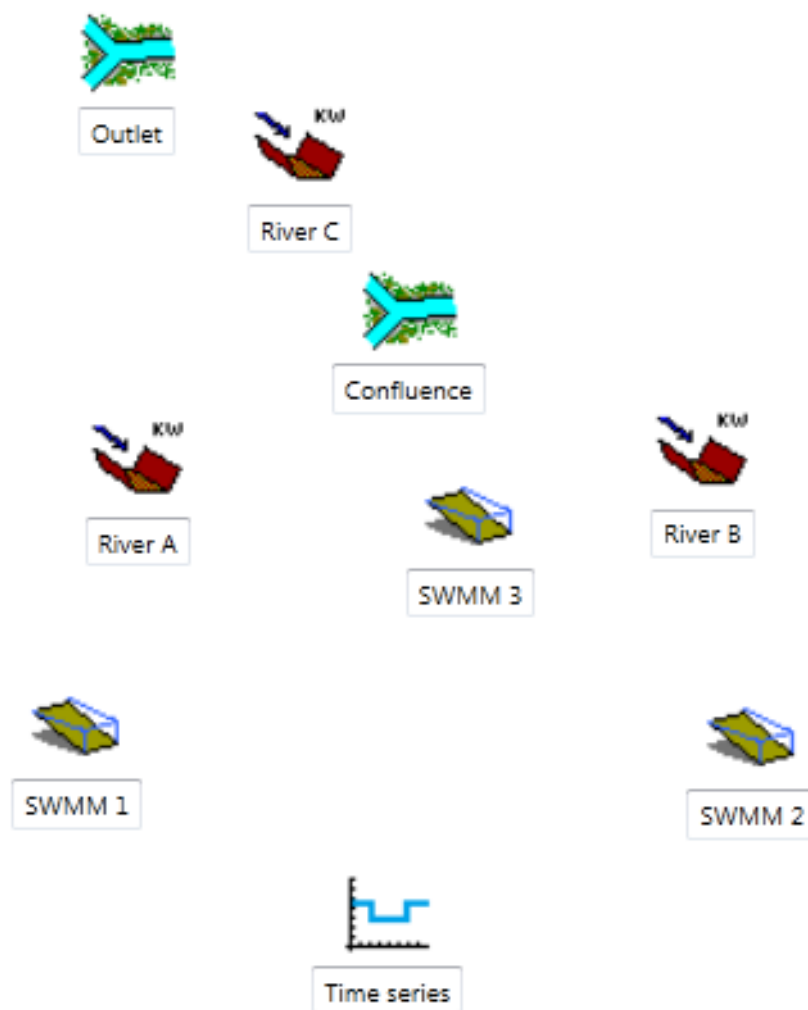


Figure 60 Graphic interface of Routing System II with the new objects

After creating the new objects, topological links or connections have to be established. To do so, it is sufficient to press once the space bar of the keyboard to pass in “connections” mode. In Editing tools, the Connections button is then automatically pressed (Figure 61). Flying over each objet, the cursor presented before as an arrow now appears as a cross. Next, click from the object « *Time Series* » to the object « *SWMM 1* », thus creating a topological link.

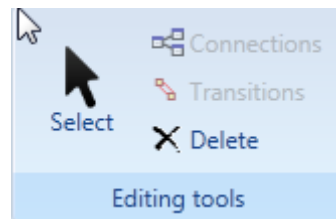


Figure 61 Editing tools frame in Connections mode

The others objects are connected in the same way. Press again the space bar of the keyboard to return to selection mode. The construction of all the model objects and the resulting topologic links is thus achieved as presented in Figure 62 and it only remains the introduction of the parameters.

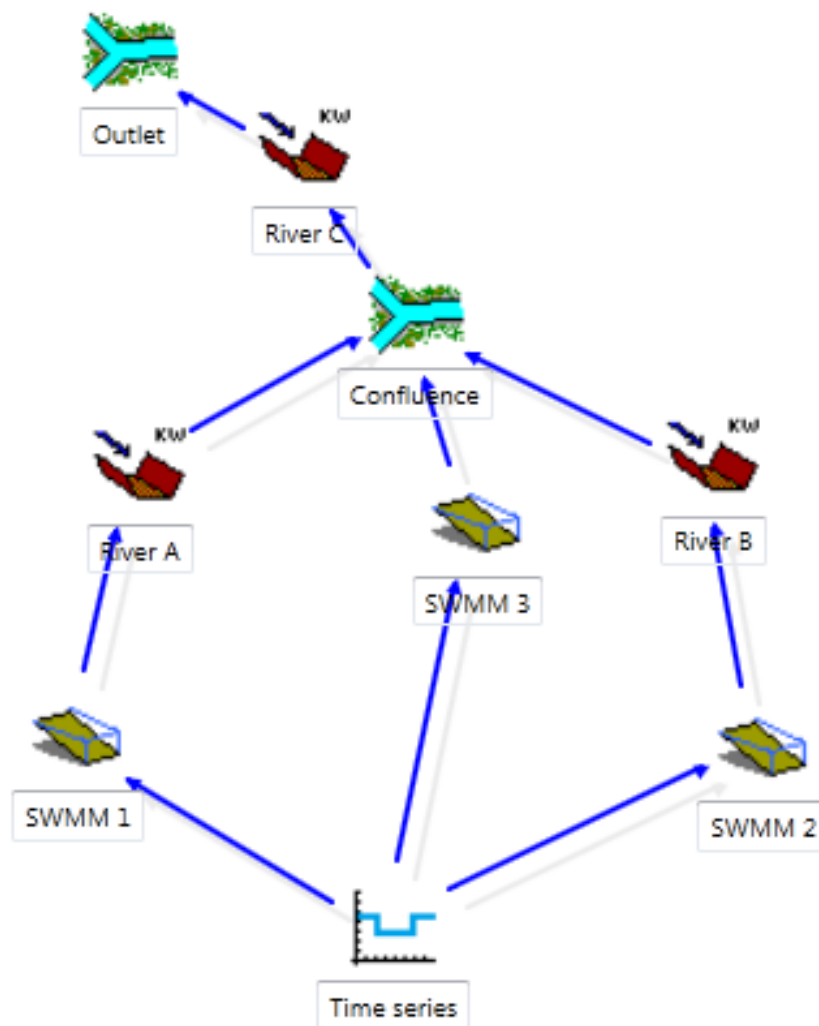


Figure 62 Topologic links between the different objects from the model

By double clicking on the links just created (blue arrows), the information transferred between « Time Series » and the three run-off surfaces as well as that between all other objects from up- to downstream is verified (Figure 62).

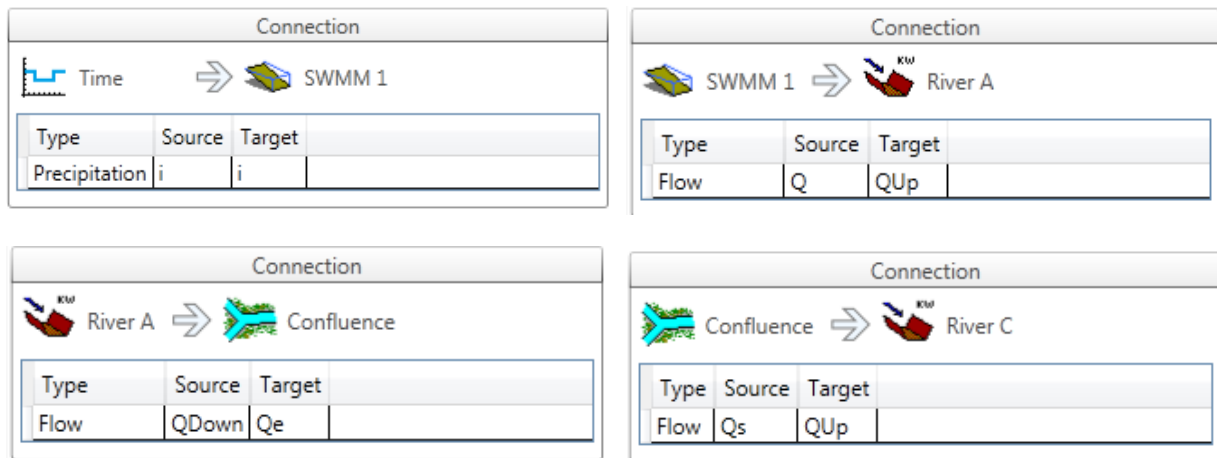


Figure 63 Examples of different connections of the presented model

In clicking double on the Time Series object, the associated frame is opened on the right of the screen and the values “ *time (s) - i (m/s)*” are introduced (Figure 64).

Figure 64 shows the 'Series' window with the 'Values' tab selected. The table displays the following data:

Time (s)	i (m/s)
0	0
3600	0.0000003
7200	0.0000004
10800	0.0000005
14400	0.0000008
18000	0.0000015
21600	0.0000023
25200	0.00000277
28800	0.0000019
32400	0.0000014
36000	0.0000009
39600	0.00000073
43200	0.0000004

Figure 64 Values of the “Temporary series”

Next, for each SWMM object (), the respective parameters (values available in Table 6) are defined by double clicking on every object and introducing them by the help of the both Parameters and Initial conditions frames. The parameters of the Rivers are introduced in the same way (Figure 65).

Parameters			
Name	Value	Unit	
A	10000000	m ²	
L	1000	m	
J0	0.01	-	
K	2	m ^{1/3} /s	

Initial conditions			
Name	Value	Unit	
HIni	0	m	

Figure 65 Parameters and initial conditions frames of SWMM 1 (left) and of River A (right)

The date parameters of the simulation are modified in Solver frame on the left of the screen (Figure 66) before the calculation. For both dates « Start » and « End » an arbitrary date is proposed, but the « End » date has to finish 24 hours later than « Start » date. The “Simulation time step” and the “Recording time step” have a value of 600 s.

Solver	
Start :	08.05.2013 00:00:00
End :	09.05.2013 00:00:00
Simulation time step :	600 s
Recording time step :	600 s
Solve	

Figure 66 Solver frame

Constructed final model can be now saved clicking in the button  and giving a name to the file (e.g. “Example1.rsm”). This way the model could be loaded later to do new simulations. Besides, the user can introduce a description of the model in the Project frame (Figure 67).

	 New	 Save
Open	 Close	 Save as
Description of the current model		
Project		

Figure 67 Project frame.

The description of the model can be added here. Before running calculation, a pre-simulation validation of the model parameterization can be made in clicking in the button  Validation (Model frame). Its report is summarized on the right of the interface.

Finally, the simulation is initiated by clicking on the button Start in the Solver frame.

Results of Example 1

In order to access to the calculation results for each object it has to be clicked two times on any of them. For example, clicking double on the object Outlet, its dialog box is opened on the right and the simulated hydrograph, being the objective of the Example 1, is shown (Figure 68).

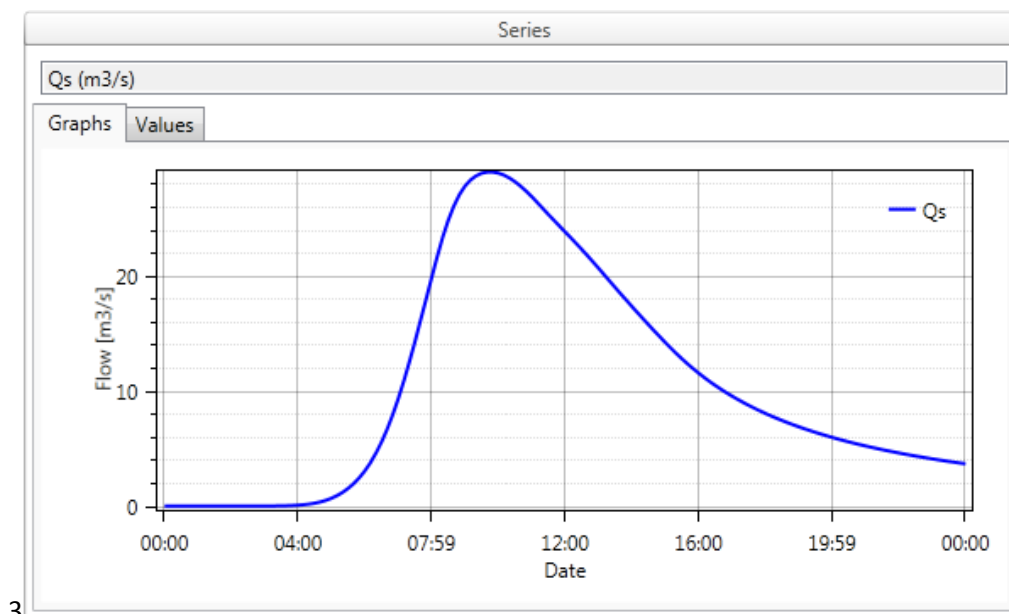


Figure 68 Results of the simulation in the outlet of the model

If we check the values (Figure 69), we can found that the maximal discharge ($29.0139 \text{ m}^3/\text{s}$) arrives at 09:50 (assuming the simulation starts at 00:00).

Series		
Qs (m3/s)		
Graphs	Values	
Date (-)	Qs (m3/s)	
08/05/2013 08:50:00	27.0465818401891	
08/05/2013 09:00:00	27.7952795049379	
08/05/2013 09:10:00	28.321520873397	
08/05/2013 09:20:00	28.6832244464403	
08/05/2013 09:30:00	28.9069267988758	
08/05/2013 09:40:00	29.012504781128	
08/05/2013 09:50:00	29.0138573707244	
08/05/2013 10:00:00	28.9219046425775	
08/05/2013 10:10:00	28.7456304497213	
08/05/2013 10:20:00	28.4927117348078	
08/05/2013 10:30:00	28.1699626826227	
08/05/2013 10:40:00	27.7835269244954	
08/05/2013 10:50:00	27.3518901315155	

Figure 69 Discharge values at outlet

9.2 Example 2 – Combined full basin with meteorological stations

The hydrological system proposed by the Example 2 includes four hydrological models of production, a GSM and three HBV models as well as the rivers of the basin. The discharge production in the subbasins area is based on given precipitations and temperatures from a database.

This expected model is represented in Figure 70.

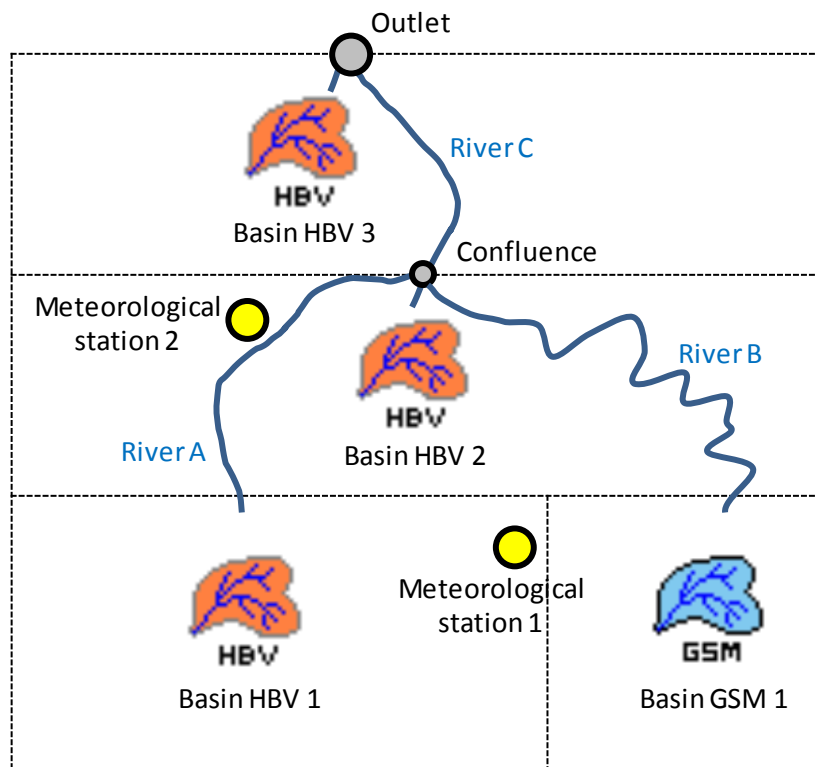


Figure 70 Model scheme

The parameters of the objects are provided in Table 6 and the precipitation and temperature data are in the database « Database manual».

Objective of Example 2

The objective of this example is to determine the hydrograph in the outlet of the system during the period between the 08.05.2013 00:00 and the 15.05.2013 00:00, the peak discharge and the peak time, as well as the discharge created at the outlet of each subbasin.

The simulation parameters are:

- Simulation time step = 600 s;
- Recording time step = 600 s.

A uniform and null ETP is assumed for this example (the user can check the selected ETP method in the RS MINERVE settings).

Table 7 Characteristics of the objects

Virtual Weather Station G1 (for GSM 1)			Virtual Weather Station H1 (for HBV 1)		
Parameters and initial conditions	Values	Units	Parameters and initial conditions	Values	Units
X	606482	m	X	603679	m
Y	101777	m	Y	102025	m
Z	3035	m	Z	2889	m
Search Radius	10000	m	Search Radius	10000	m
No. min. of stations	1	-	No. min. of stations	1	-
Gradient P	0	m/s/m	Gradient P	0	m/s/m
Gradient T	-0.0065	C/m	Gradient T	-0.0065	C/m
Gradient ETP	0	m/s/m	Gradient ETP	0	m/s/m
Coeff P	1	-	Coeff P	1	-
Coeff T	0	-	Coeff T	0	-
Coeff ETP	1	-	Coeff ETP	1	-

GSM 1			HBV 1		
Parameters and initial conditions	Values	Units	Parameters and initial conditions	Values	Units
A	4.00E+06	m ²	A	1.00E+07	m ²
An	6	mm/°C/day	CFMax	6	mm/°C/day
ThetaCri	0.1	-	CFR	1	-
bp	0.0125	s/m	CWH	0.1	-
Tcp1	0	°C	TT	2	°C
Tcp2	6	°C	TTInt	2	°C
Tcf	0	°C	TTSM	0	°C
AgI	7	mm/°C/day	Beta	2.5	-
Tcg	0	°C	FC	250	mm
Kgl	1.4	1/d	PWP	325	mm
Ksn	1.7	1/d	SUMax	50	mm
HsnowIni	0.2	m	Kr	0.25	1/day
ThetaIni	0	-	Ku	0.15	1/day
QsnowIni	0.1	m ³ /s	KI	0.05	1/day
QglacierIni	0	m ³ /s	Kperc	0.15	1/day
			HsnowIni	0.02	m
			WHIni	0	-
			HumIni	0.23	m
			SUIni	0.05	m
			SLIni	0.15	m

Table 8 Characteristics of the objects

Virtual Weather Station H2 (for HBV 2)			Virtual Weather Station H3 (for HBV 3)		
Parameters and initial conditions	Values	Units	Parameters and initial conditions	Values	Units
X	604908	m	X	604837	m
Y	103668	m	Y	105120	m
Z	2406	m	Z	1947	m
Search Radius	10000	m	Search Radius	10000	m
No. min. of stations	1	-	No. min. of stations	1	-
Gradient P	0	m/s/m	Gradient P	0	m/s/m
Gradient T	-0.0065	C/m	Gradient T	-0.0065	C/m
Gradient ETP	0	m/s/m	Gradient ETP	0	m/s/m
Coeff P	1	-	Coeff P	1	-
Coeff T	0	-	Coeff T	0	-
Coeff ETP	1	-	Coeff ETP	1	-

HBV 2			HBV 3		
Parameters and initial conditions	Values	Units	Parameters and initial conditions	Values	Units
A	8.00E+06	m2	A	9.00E+06	m2
CFMax	7	mm/°C/day	CFMax	7	mm/°C/day
CFR	1	-	CFR	1	-
CWH	0.1	-	CWH	0.1	-
TT	2	°C	TT	2	°C
TTInt	2	°C	TTInt	2	°C
TTSM	0	°C	TTSM	0	°C
Beta	2.3	-	Beta	2.3	-
FC	275	mm	FC	280	mm
PWP	360	mm	PWP	370	mm
SUMax	55	mm	SUMax	60	mm
Kr	0.3	1/day	Kr	0.35	1/day
Ku	0.1	1/day	Ku	0.1	1/day
Kl	0.05	1/day	Kl	0.05	1/day
Kperc	0.15	1/day	Kperc	0.15	1/day
HsnowIni	0.01	M	HsnowIni	0	m
WHIni	0	-	WHIni	0	-
HumIni	0.2	M	HumIni	0.22	m
SUIni	0.01	M	SUIni	0.02	m
SLIni	0.1	M	SLIni	0.1	m

Table 9 Characteristics of the objects

River A			River B		
Parameters and initial conditions	Values	Units	Parameters and initial conditions	Values	Units
Lenght (L)	3000	m	Lenght (L)	4000	m
bed width (BO)	6	m	bed width (BO)	4	m
Side bank rel. (m)	1	-	Side bank rel. (m)	1	-
Slope (JO)	0.001	-	Slope (JO)	0.005	-
Strickler (K)	30	m ^{1/3} /s	Strickler (K)	30	m ^{1/3} /s
Initial discharge (Qini)	0	m ³ /s	Initial discharge (Qini)	0	m ³ /s

River C		
Parameters and initial conditions	Values	Units
Lenght (L)	2000	m
bed width (BO)	7	m
Side bank rel. (m)	1	-
Slope (JO)	0.001	-
Strickler (K)	30	m ^{1/3} /s
Initial discharge (Qini)	0	m ³ /s

Besides, two meteorological real stations are included in the data base

Table 10 Characteristics of the meteorological real stations

Meteorological Station 1 (Database)			Meteorological Station 2 (Database)		
Parameters and initial conditions	Values	Units	Parameters and initial conditions	Values	Units
X	605709	m	X	604002	m
Y	102143	m	Y	103517	m
Z	2756	m	Z	2387	m

Resolution of Example 2

First of all, the subcatchment with HBV  and GSM  models will be set up. Then, the three rivers  (with Reach Kinematic) and the two junctions  are also added as presented in Figure 70 (more details are given in Example 1 for model construction, including the link between each object and their parameterization).

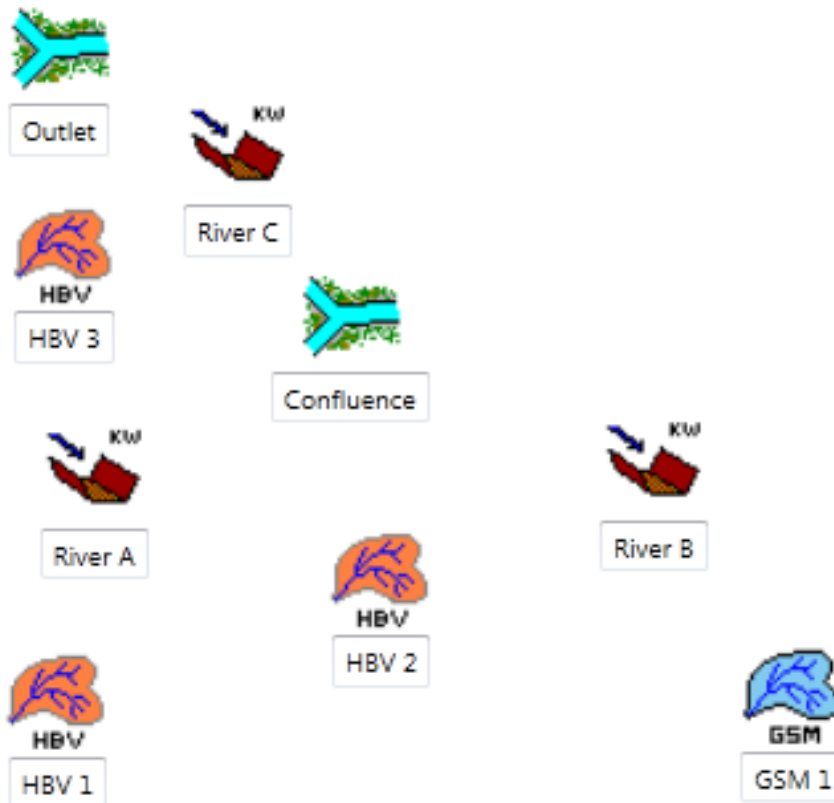


Figure 71 Topologic links between the different objects

After that, the models are linked from upstream to downstream and the relations created can be visualized by double clicking on each blue arrow (Figure 72, Figure 73, Figure 74).

X

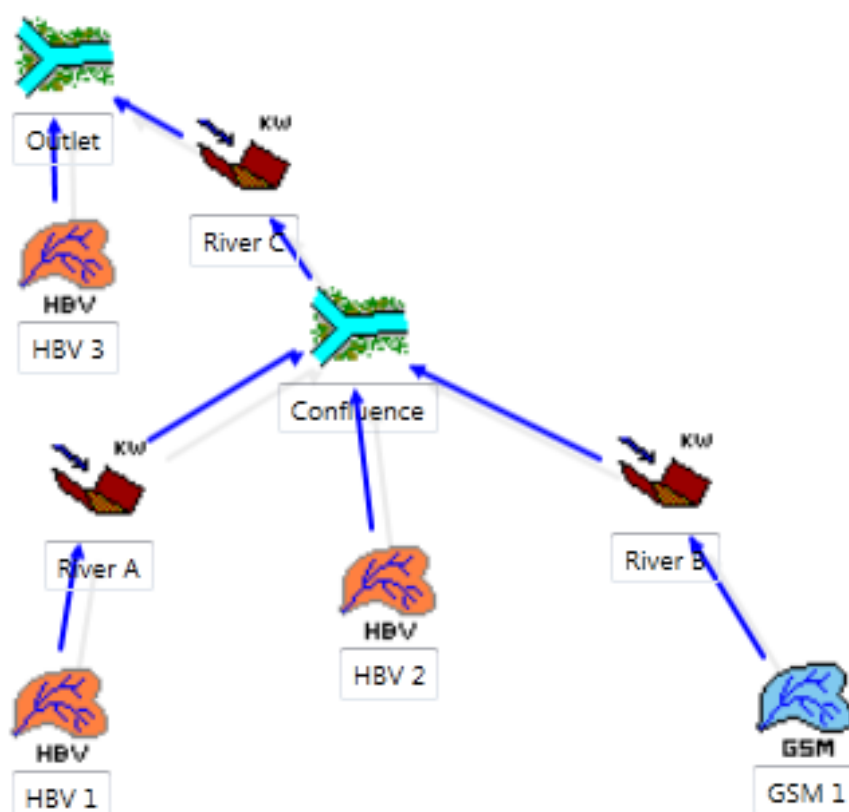


Figure 72 Relations between the objects

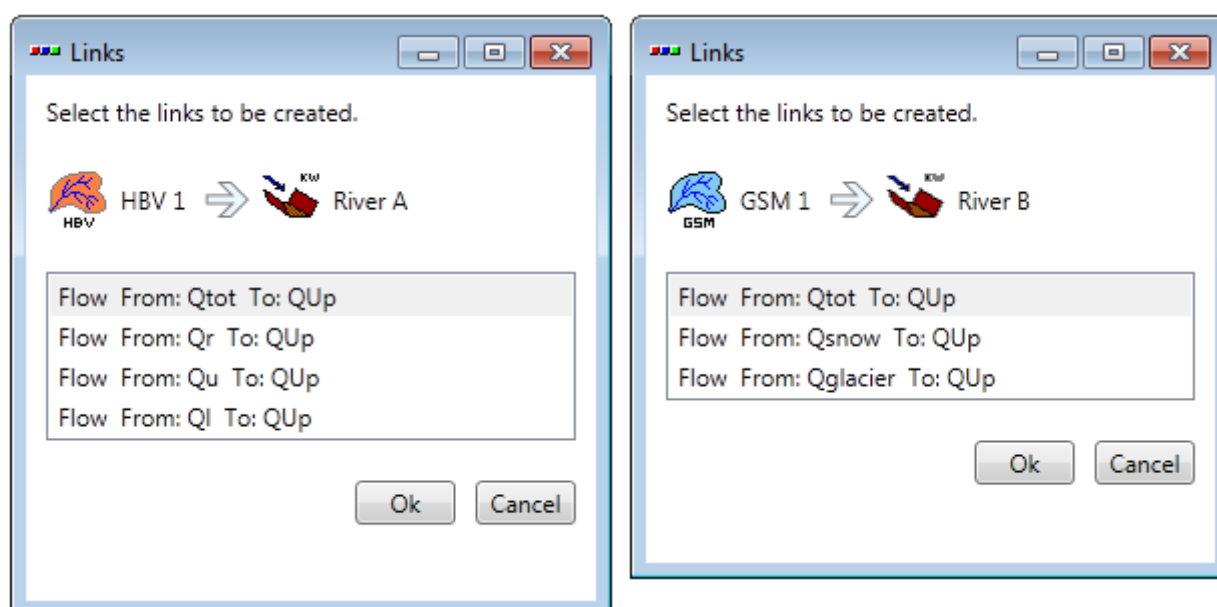
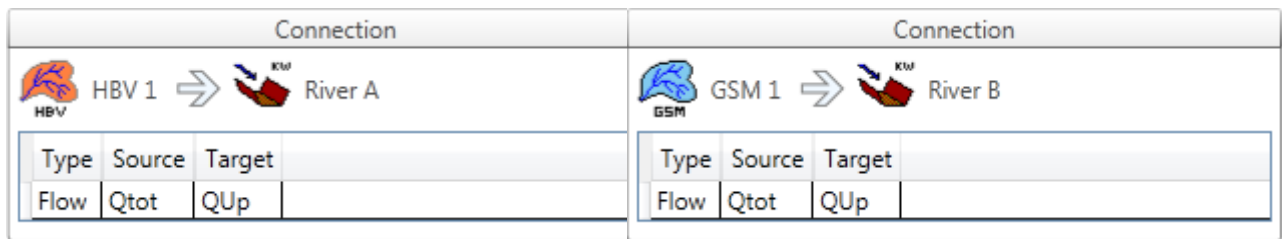


Figure 73 Possible outputs transfers between objects

**Figure 74** Connections between objects

The parameters associated to each object are then introduced (values available in Table 7, Table 8 and Table 9). The result is presented for both HBV 1 and GSM 1 models in Figure 75.

Parameters				Parameters			
Name	Value	Unit		Name	Value	Unit	
A	10000000	m2		A	4000000	m2	
CFMax	6	mm/°C/day		An	6	mm/°C/day	
CFR	1	-		ThetaCri	0.1	-	
CWH	0.1	-		bp	0.0125	s/m	
TT	2	°C		Tcp1	0	°C	
TTInt	2	°C		Tcp2	6	°C	
TISM	0	°C		Tcf	0	°C	
Beta	2.5	-		AgI	7	mm/°C/day	
FC	250	mm		Tcg	0	°C	
PWP	325	mm		Kgl	1.4	1/d	
SUMax	50	mm		Ksn	1.7	1/d	
Kr	0.25	1/d		Initial conditions			
Ku	0.15	1/d		Name	Value	Unit	
KI	0.05	1/d		HsnowIni	0.2	m	
Kperc	0.15	1/d		ThetaIni	0	-	
Initial conditions				QsnowIni	0.1	m3/s	
Name	Value	Unit		QglacierIni	0	m3/s	
HsnowIni	0.02	m					
WHIni	0	-					
HumIni	0.23	m					
SUIni	0.05	m					
SLIni	0.15	m					

Figure 75 Parameters of the HBV 1 model (left) and the GSM 1 model (right)

Secondly, virtual weather stations are inserted. For its accomplishment, 4 Virtual Weather Stations  are created and connected according to the Figure 76. The topology of the relations created in this case is detailed in Figure 77. Then the parameters are introduced (Figure 78) with the available values in Table 8.

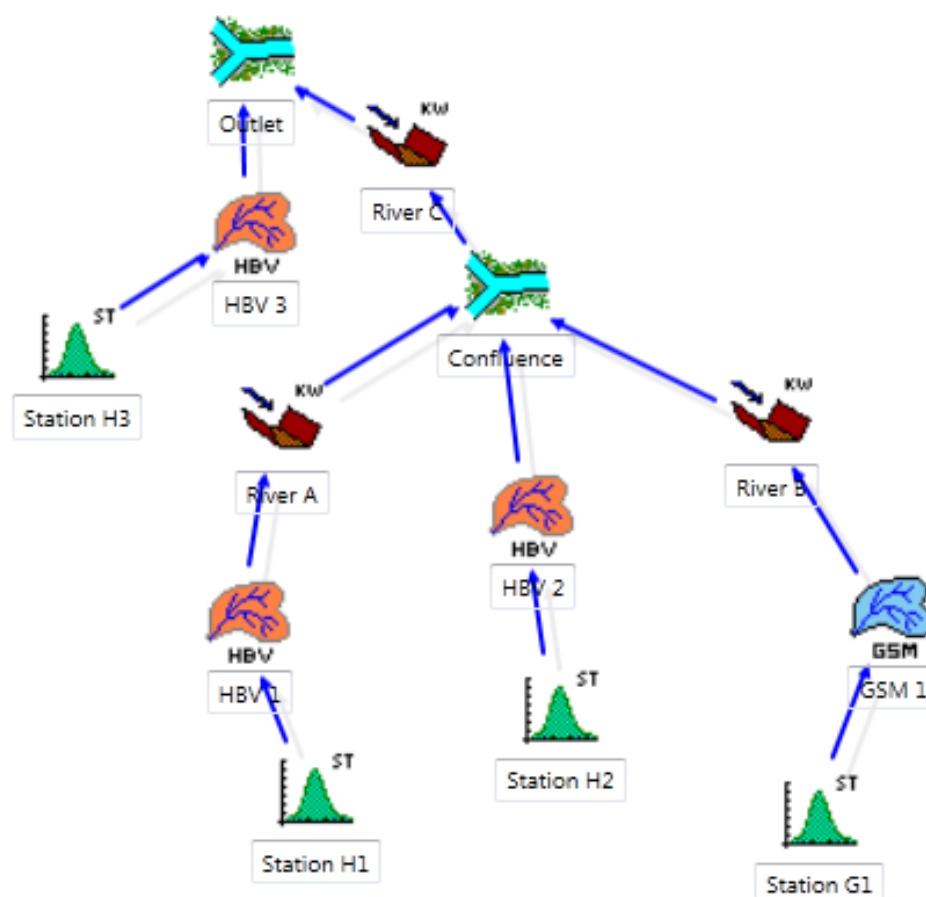
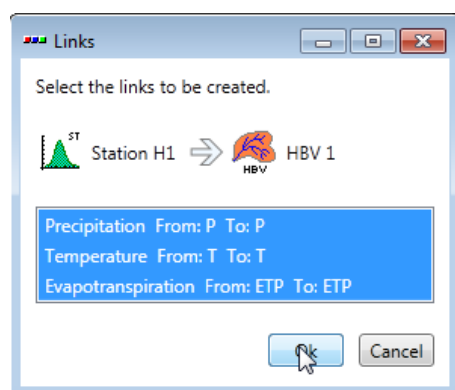
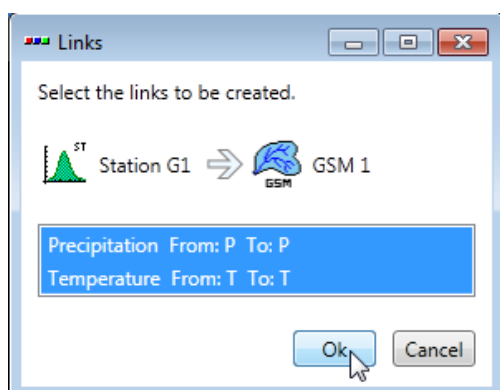


Figure 76 Topology of the full model: production, transfer then transport



Connection			
 Station H1	⇒	 HBV 1	
Type	Source	Target	
Precipitation	P	P	
Temperature	T	T	
Evapotranspiration	ETP	ETP	



Connection			
 Station G1	⇒	 GSM 1	
Type	Source	Target	
Precipitation	P	P	
Temperature	T	T	

Figure 77 Topologic links between the different objects

Parameters			
Name	Value	Unit	
X	603679	m	
Y	102025	m	
Z	2889	masl	
Search Radius	10000	m	
No. min. of stations	1	-	
Gradient P	0	m/s/m	
Gradient T	-0.0065	C/m	
Gradient ETP	0	m/s/m	
Coeff P	1	-	
Coeff T	0	-	
Coeff ETP	1	-	

Figure 78 Parameters of the Virtual Weather Station H1 (for HBV 1)

Constructed model can be now saved clicking in the button  and giving a name to the .rsm file (e.g. "Example2.rsm").

Next, the meteorological data have to be loaded: the dialog box of the database is opened clicking in  (Figure 79) for loading the corresponding database file ("Database manual.dbx").

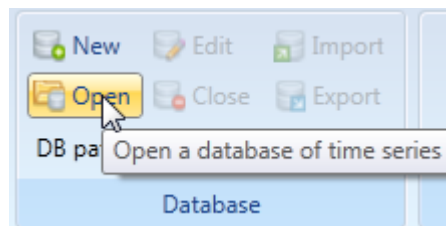


Figure 79 Database frame

The user can click in  for visualizing or modifying the database (Figure 80).

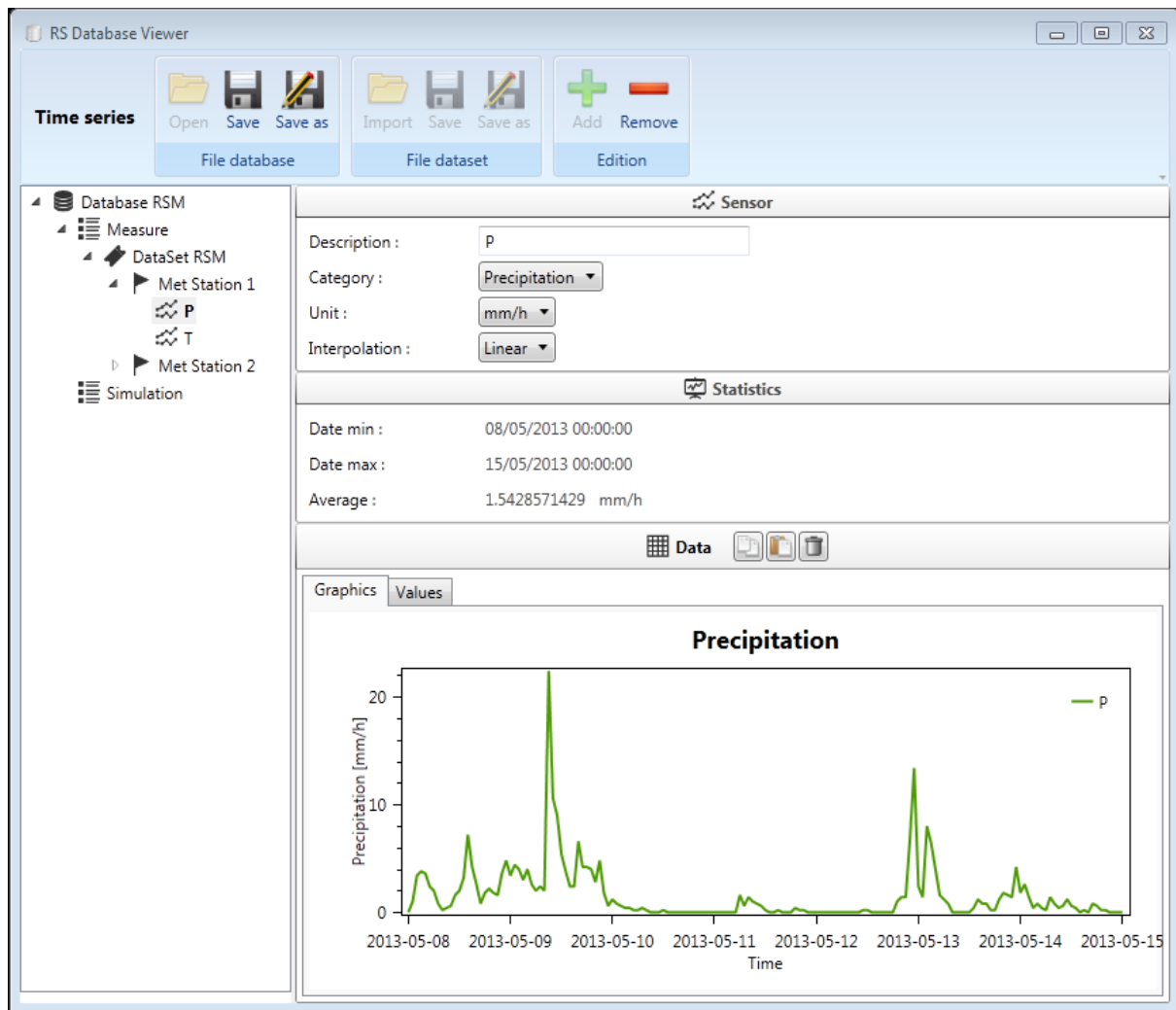


Figure 80 Database of the model

Once the database loaded, the user can connect the database to the hydrological model. For achieving this purpose, the user has to choose the correct data source in the corresponding frame (Figure 81): the group “Measure” and the dataset “DataSet Example 2and3” for the current example. Since no source, *TurbineDB*, reservoir or consumer objects exist in the model, it is not necessary to fill up their data sources.

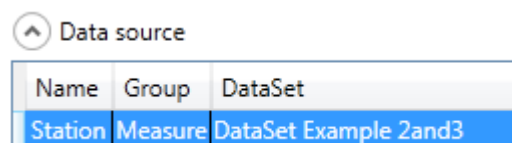


Figure 81 Data source used for connecting the model to the database

Finally, and after achieve a simulation, the weight of each meteorological real station can be checked by clicking at one Virtual Weather station of the hydrological model (Figure 82).

Selected stations and their respective weight	
Precipitation	
Name	Weight
Met Station 1	0.36
Met Station 2	0.64
Temperature	
Name	Weight
Met Station 1	0.36
Met Station 2	0.64
ETP (No data)	

Figure 82 Weight of each meteorological station for the Virtual Weather Station H1

The pre-simulation validation ( Validation) allows to valid the model. If the message: “Model ‘Example 2’ is valid” appears, the simulation can be started by clicking in the button Start.

Results of Example 2

Once finished the calculation, the hydrograph in the outlet of the system, among others, can be visualized (Figure 83).

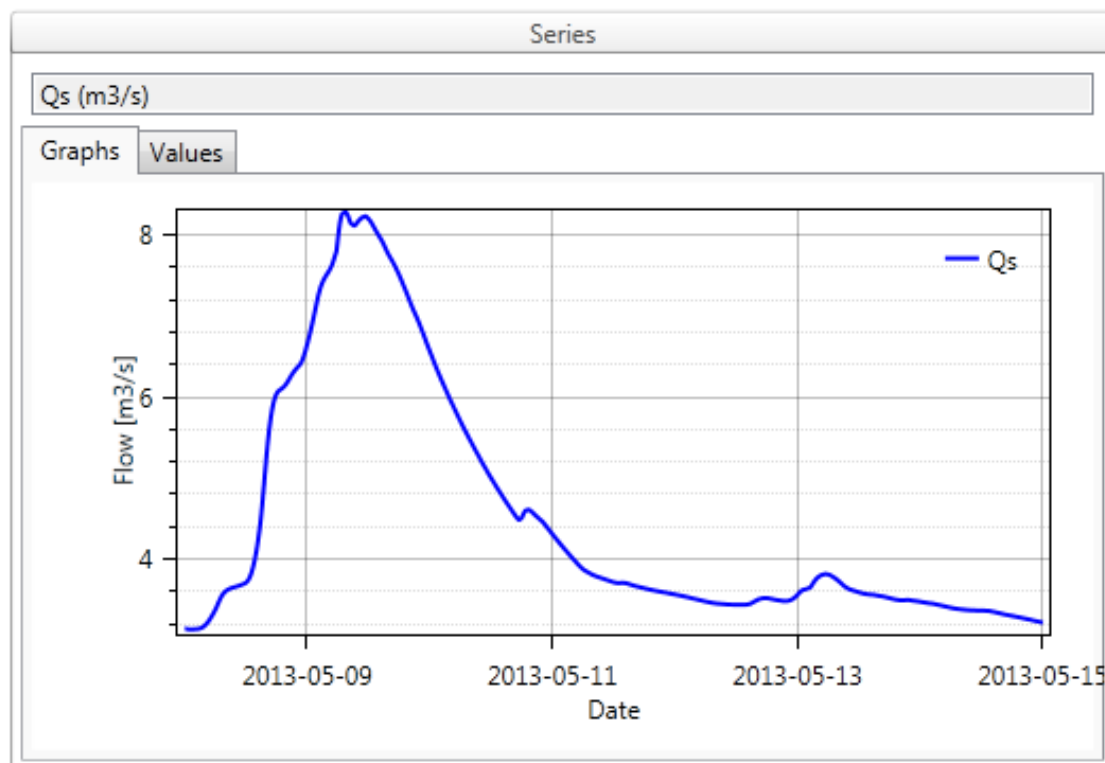


Figure 83 Hydrograph in the outlet of the system

If we check the values (Figure 84), we can find that the maximal discharge arrives on May 9, 2013 at 07:20 and the discharge value is 8.306 m³/s.

Series		
Qs (m³/s)		
Graphs	Values	
Date (-)	Qs (m³/s)	
09/05/2013 06:00:00	7.9975927295	
09/05/2013 06:10:00	8.0862434755	
09/05/2013 06:20:00	8.1601150309	
09/05/2013 06:30:00	8.2183738050	
09/05/2013 06:40:00	8.2605436239	
09/05/2013 06:50:00	8.2860894701	
09/05/2013 07:00:00	8.2947820648	
09/05/2013 07:10:00	8.3009328420	
09/05/2013 07:20:00	8.3060171814	
09/05/2013 07:30:00	8.3029952104	
09/05/2013 07:40:00	8.2893707140	
09/05/2013 07:50:00	8.2682719625	
09/05/2013 08:00:00	8.2411084322	

Figure 84 Discharge values at outlet

All the simulated variables of the model (including the discharge in each sub-basin outlet) can be visualized (Figure 85 and Figure 86) clicking on the Plot frame and in selecting the series to draw as presented in chapter 4.2. Finally you can export the selection results in excel format clicking in “Export results to...” in the series frame.

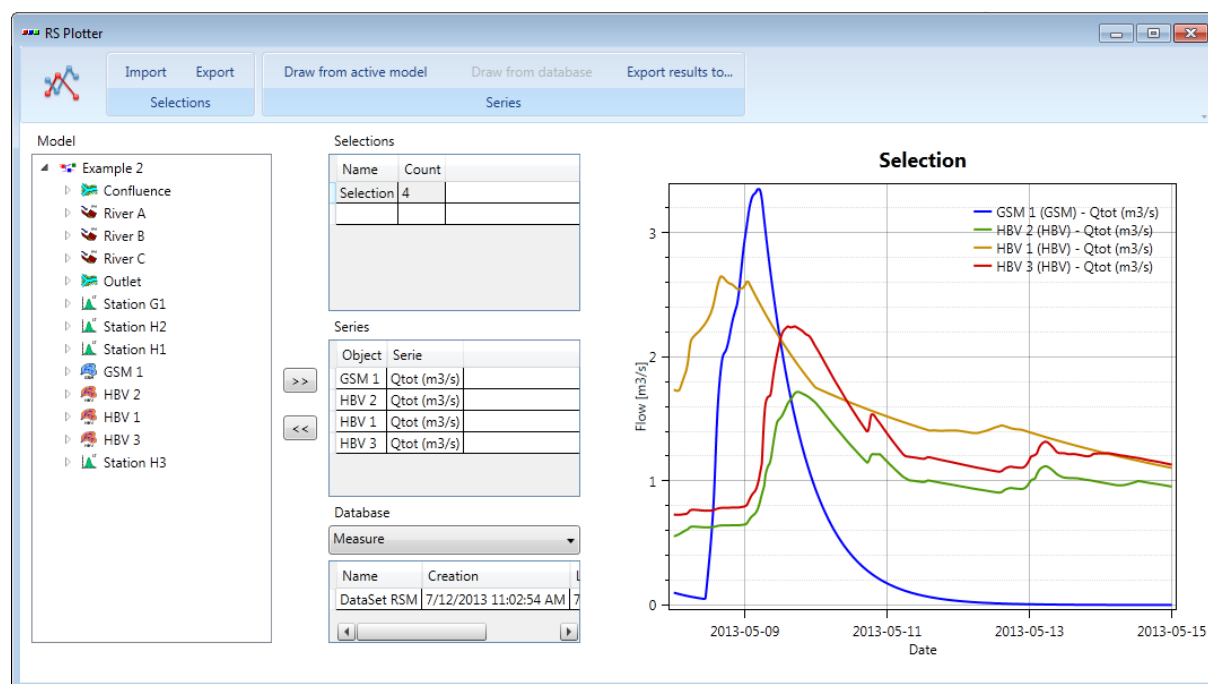


Figure 85 Selection and Plots with the hydrographs at the outlet for each sub-basin of the system

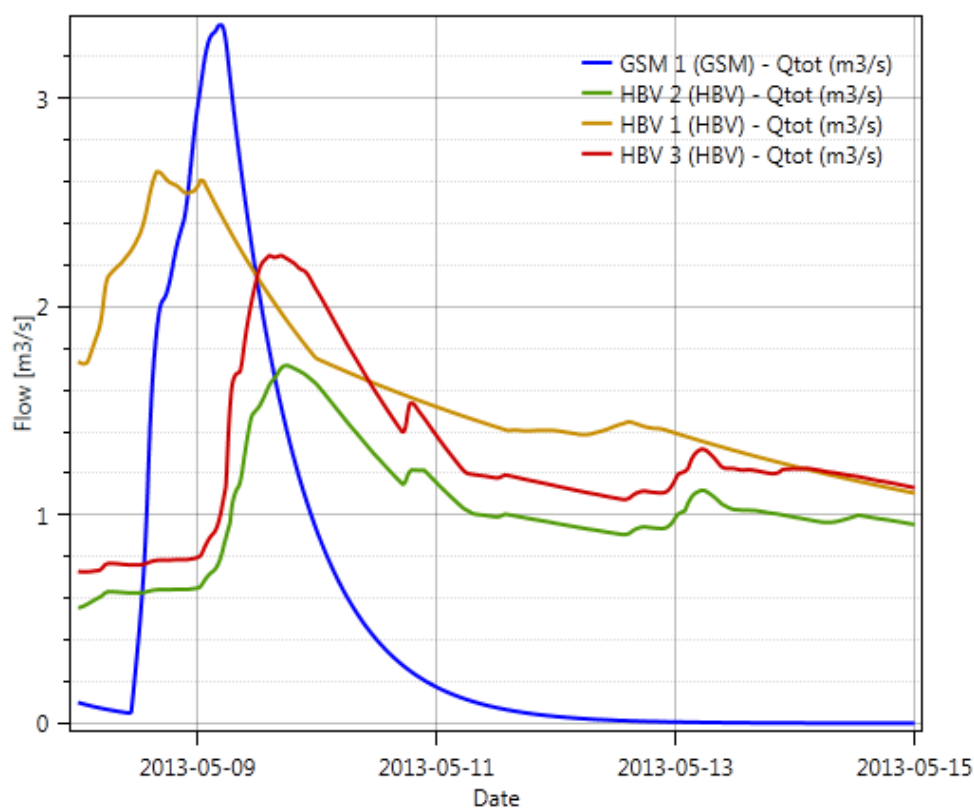


Figure 86 Hydrographs at the outlet for each sub-basin of the system

9.3 Example 3 – Equipped basin with a hydropower scheme

This example, allows showing the potential of RS MINERVE for equipped basins. The model starts with the previous model built in Example 2 and adds a hydropower scheme as well as a supplementary basin with an intake. The complete model is presented in Figure 87.

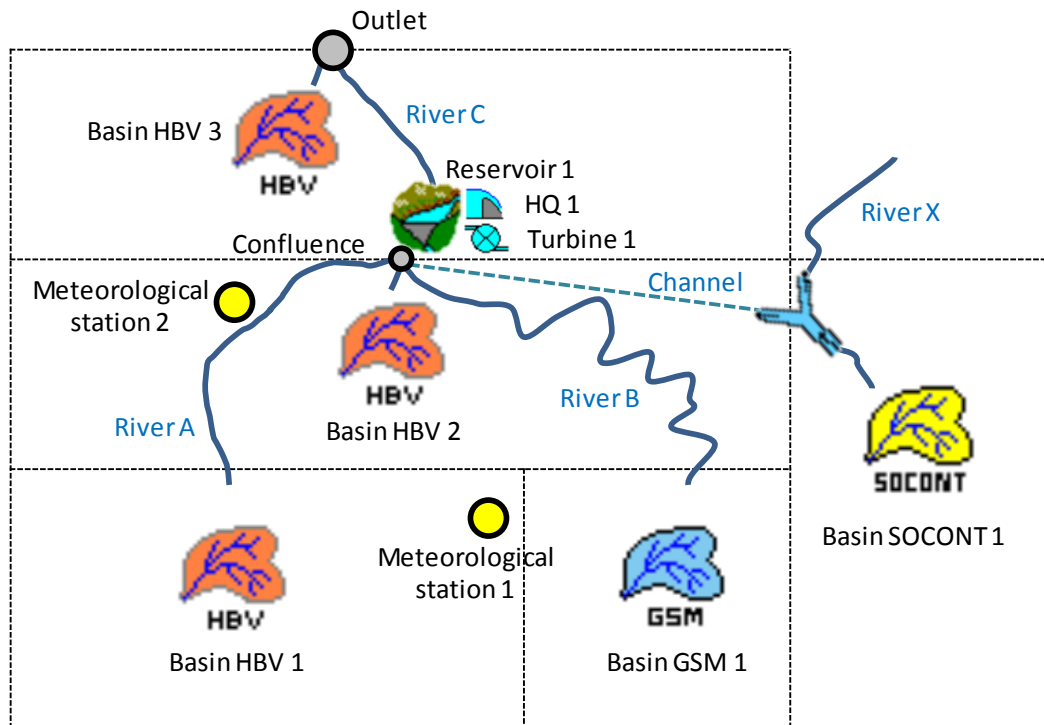


Figure 87 Model scheme

HBV 1, HBV 2 and GSM 1 basins flow through the Reservoir 1. Intake located downstream of a SOCONT model provides supplementary discharge up to $2 \text{ m}^3/\text{s}$. It is assumed that the propagation in the channel is insignificant and thus it is not necessary to include it in the model (in other case, we could built it with the Reach Kinematic object).

The reservoir includes a turbine and a spillway. The turbine generates electricity as long as it is possible for a capacity of $1 \text{ m}^3/\text{s}$. These two reservoir outflows flow in the River C up the outlet, where they are joined by the production of HBV 3 sub-basin. All the parameters of the different objects are provided in Table 11. The temperature and precipitation data are in the database « Database manual ». A uniform and null ETP is assumed for this example (the user can check the selected ETP method in the RS MINERVE settings).

Objective of Example 3

Part A

The wanted result for this example is the inflow in the reservoir, the spillway discharge and the hydrograph in the outlet of the model for the period between the 08.05.2013 00:00 and the 15.05.2013 00:00 (as well as the peak discharge and the peak time).

Part B

Second issue aims to know if the reservoir could be managed in order to reduce the peak in the outlet of the system. The objective of this extension is to implement a facility to release water for preventive purposes.

Table 11 Characteristics of the objects

Virtual Weather Station S1 (for SOCONT 1)			SOCONT 1		
Parameters and initial conditions	Values	Units	Parameters and initial conditions	Values	Units
X	608017	m	A	8000000	m ²
Y	102861	m	An	7	mm/°C/day
Z	2796	m	ThetaCri	0.1	-
Search Radius	10000	m	Bp	0.0125	s/m
No. min. of stations	1	-	Tcp1	0	°C
Gradient P	0	m/s/m	Tcp2	4	°C
Gradient T	-0.0065	C/m	Tcf	0	°C
Gradient ETP	0	m/s/m	HGR3Max	0.3	m
Coeff P	1	-	KGR3	0.005	1/s
Coeff T	0	-	L	800	m
Coeff ETP	1	-	J0	0.01	-
			Kr	2	m ^{1/3} /s
			HsnowIni	0.1	m
			Thetalni	0	-
			HGR3Ini	0.1	m
			HrIni	0	m

Table 12 Characteristics of the objects

Reservoir 1		
H (m a.s.l.)	Vol (m³)	
2110	0	
2115	7.92E+05	
2120	2.09E+06	
2125	3.96E+06	
2130	6.48E+06	
2135	9.90E+06	
Parameters	Values	Units
Hini	2127.3	masl
Spillway 1 (with HQ)		
H (m a.s.l.)	Q (m³)	
2128	0	
2129	10	
2130	30	
2132	100	
2135	250	
Turbine time series 1		
Time (s)	Q (m³/s)	
0	1	
3.00E+06	1	
Diversion 1		
Qup (m3/s)	Qdiverted (m3/s)	
0	0	
2	2	
10	2	

Additionally, initial discharge (Qini) of River C is in this case 1 m³/s.

Resolution of Example 3 – Part A

In the first place, the model of the Example 2 is opened. The connection between the “Confluence” and the River C is erased and objects Virtual Weather Station , SOCONT , Reservoir , Spillway , Turbine , Times Series  and Junction  are added, as presented in Figure 88.

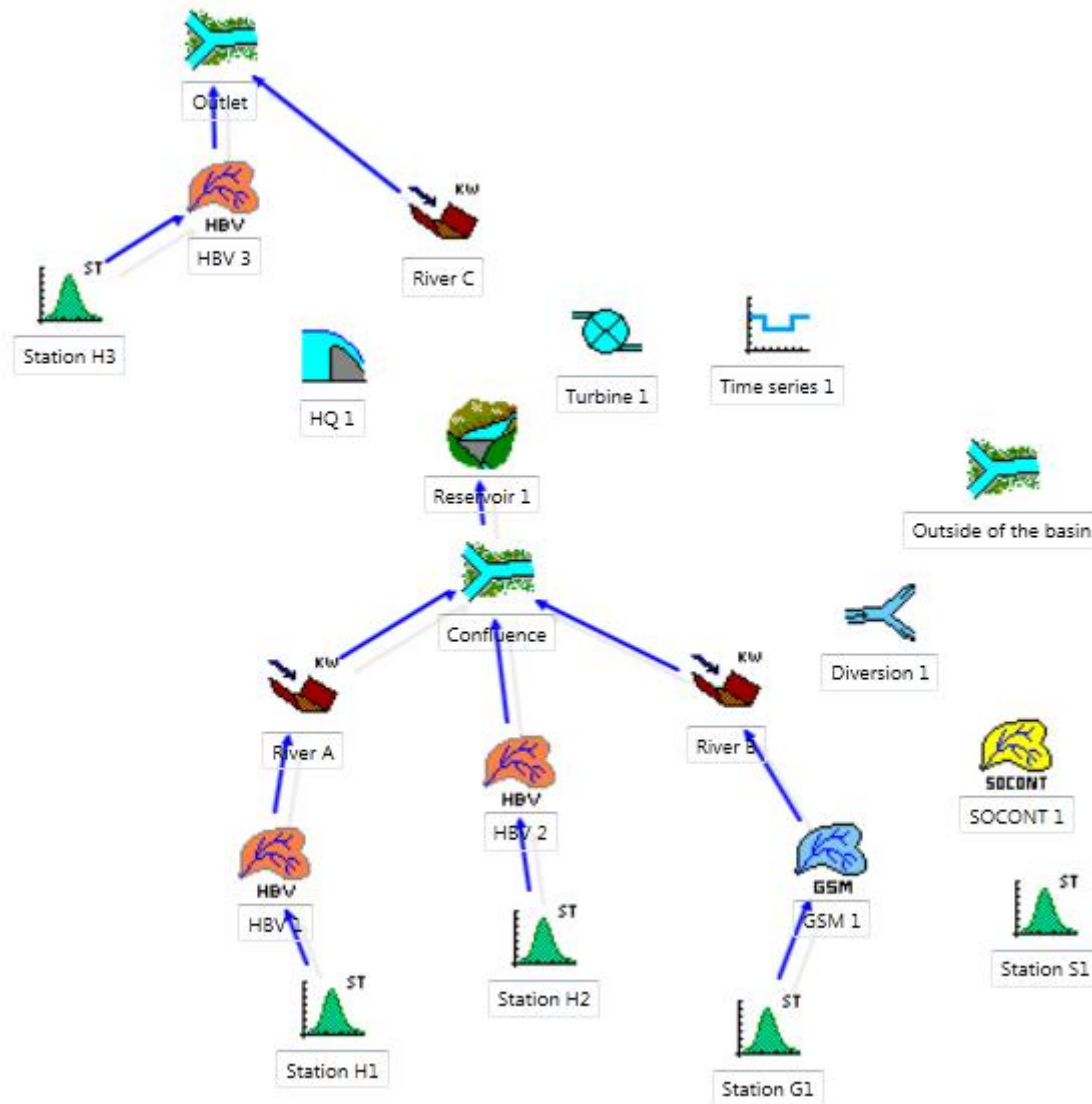


Figure 88 Construction of the Example 3 model on the basis of Example 2

New objects are always linked from upstream to downstream (e.g.: SOCONT 1 to Diverion 1, Diverion 1 to Confluence ($Q_{diverted}$) and to Outside of the Basin (Q_{down}), Reservoir 1 to HQ 1, Reservoir 1 to Turbine 1, Time Series 1 to Turbine 1, Turbine 1 to River C, etc). After creating the links (Figure 89), the news relations can be visualized by double clicking on each blue arrow (Figure 90 and Figure 91).

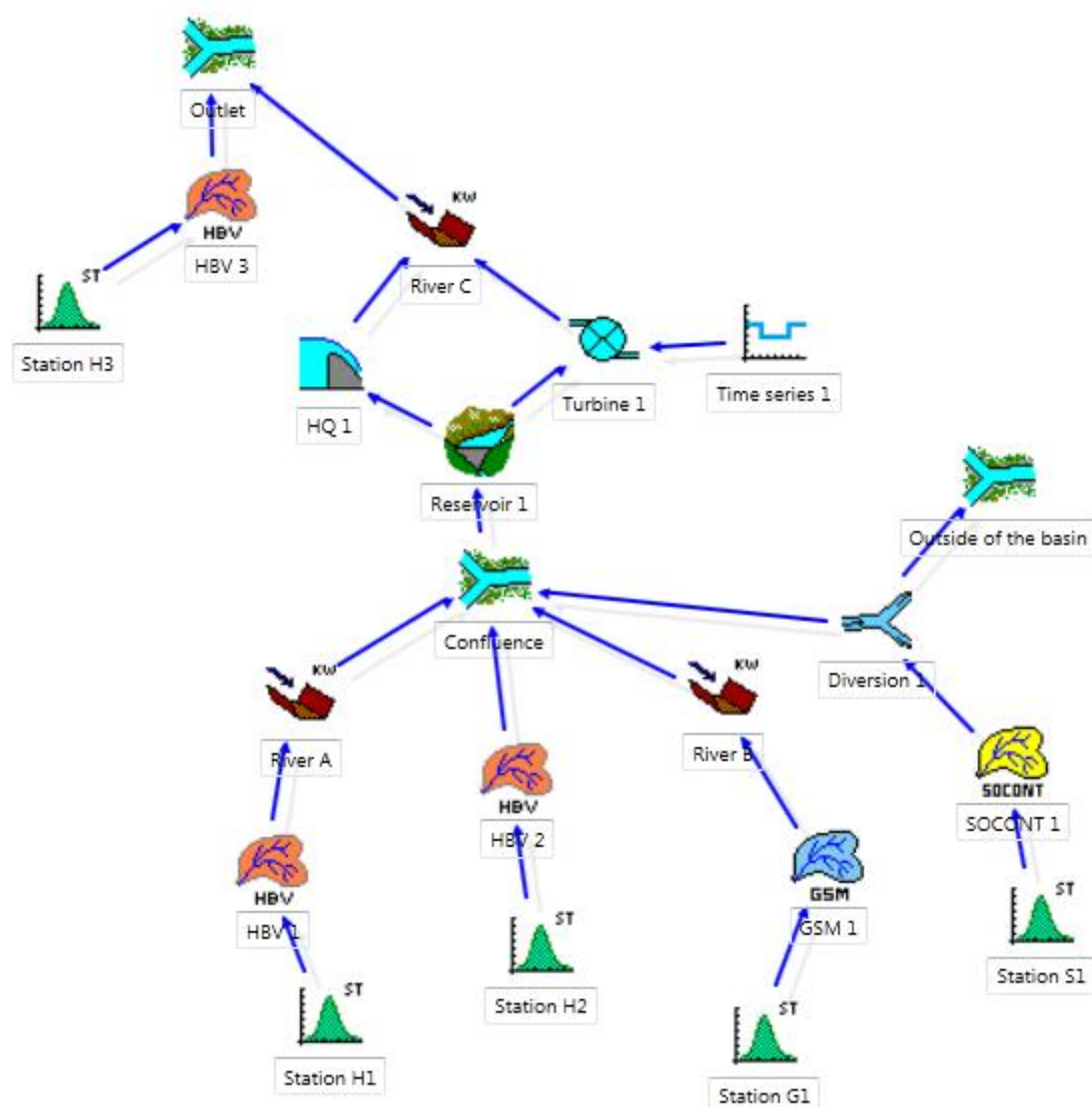


Figure 89 Typology of the new model

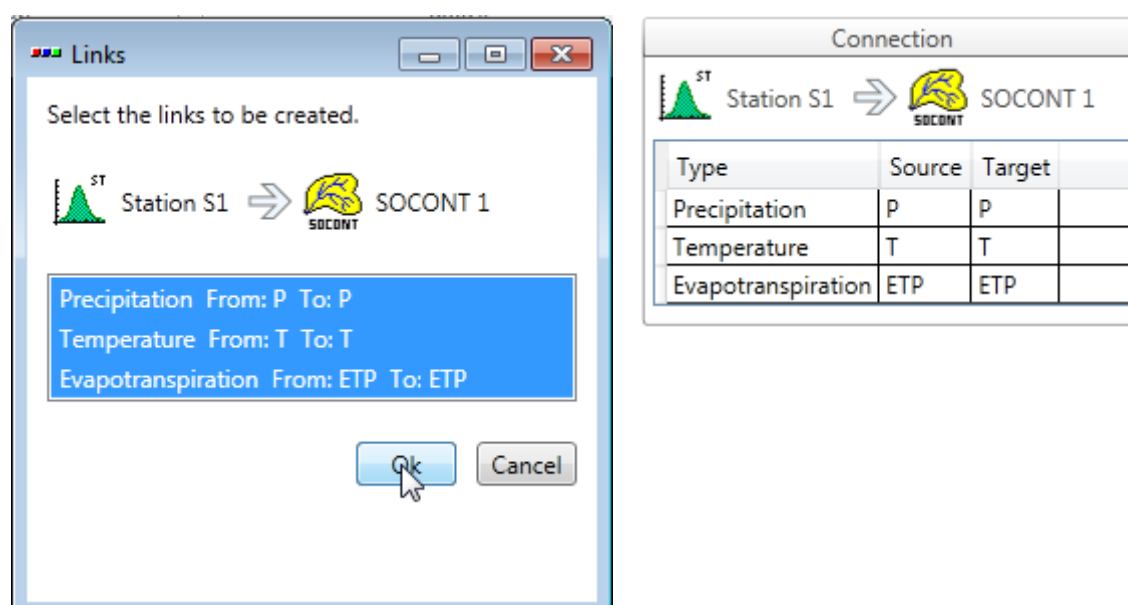
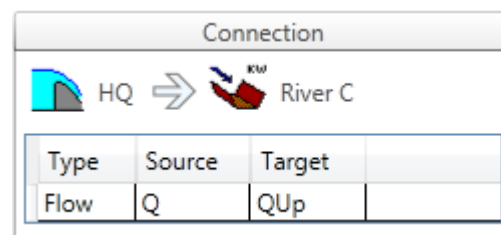
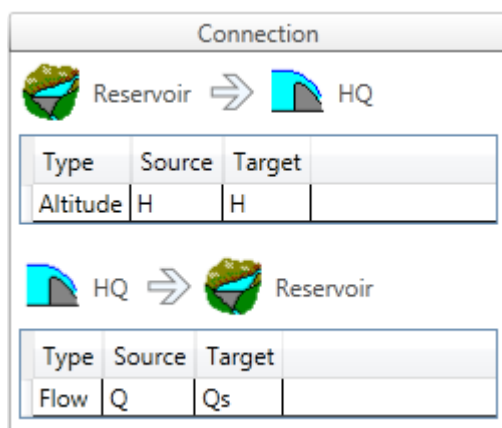
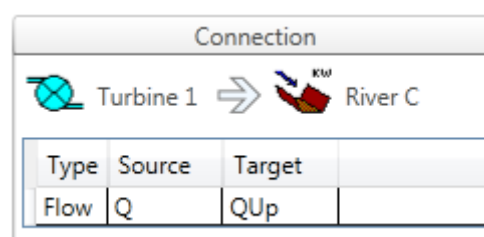
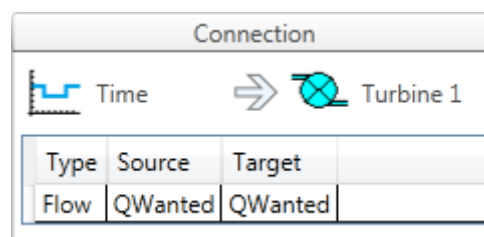
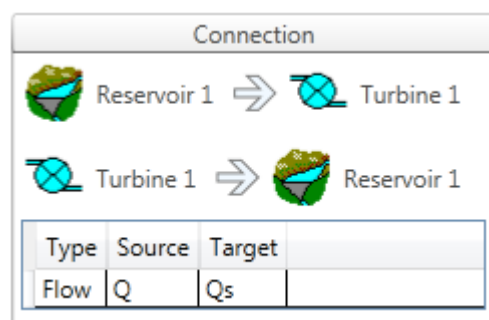


Figure 90 Relations for Virtual Weather Station S1 and SOCONT 1 objects

Reservoir relations



Turbine relations



Intake relations

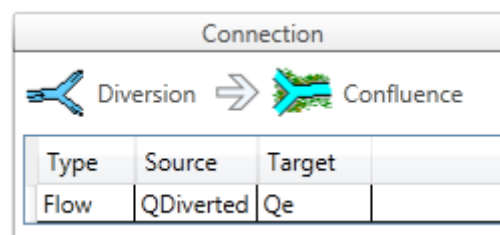
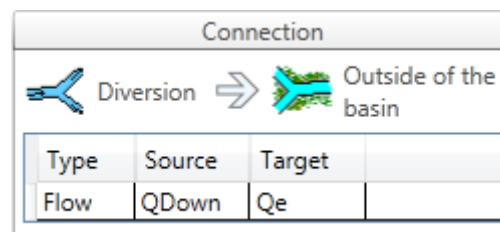
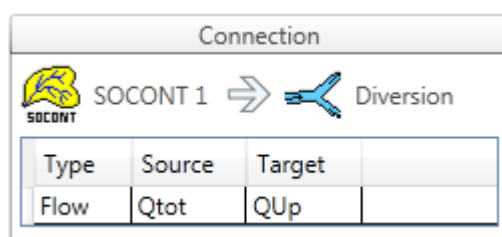


Figure 91 Connections between objects

The introduced parameters of new objects Diversion 1, Reservoir 1, HQ 1 and Time Series 1 are presented in Figure 92 to Figure 95.

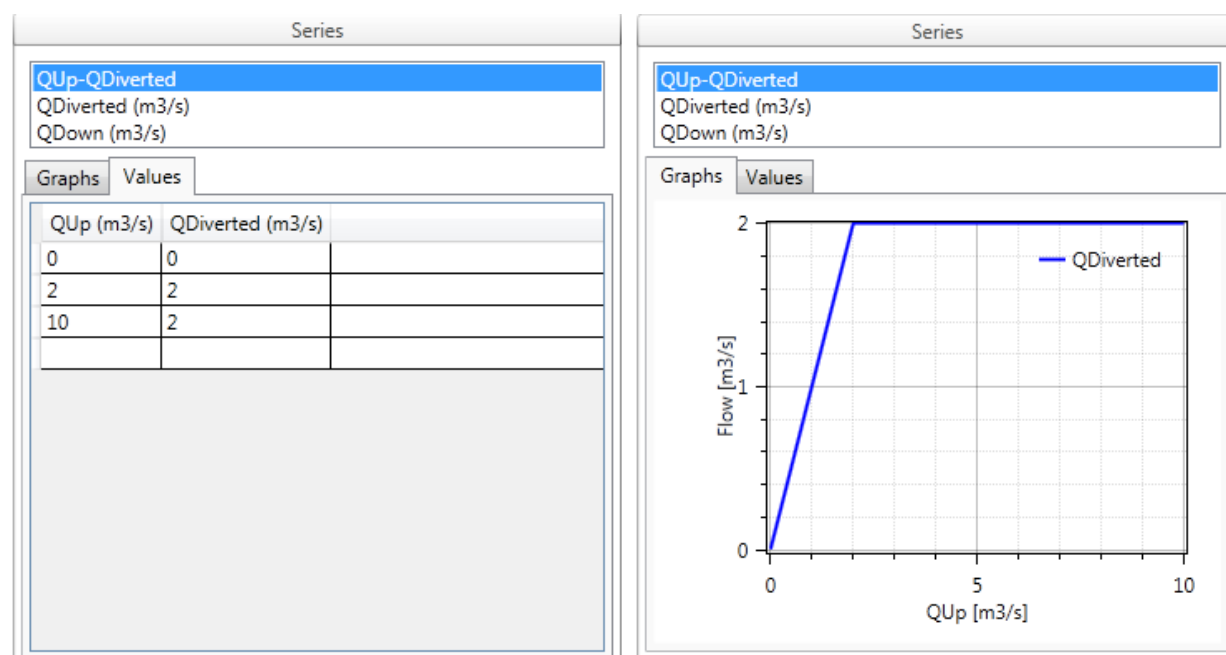


Figure 92 Relation Qup-Qdiverted introduced in the Diversion 1

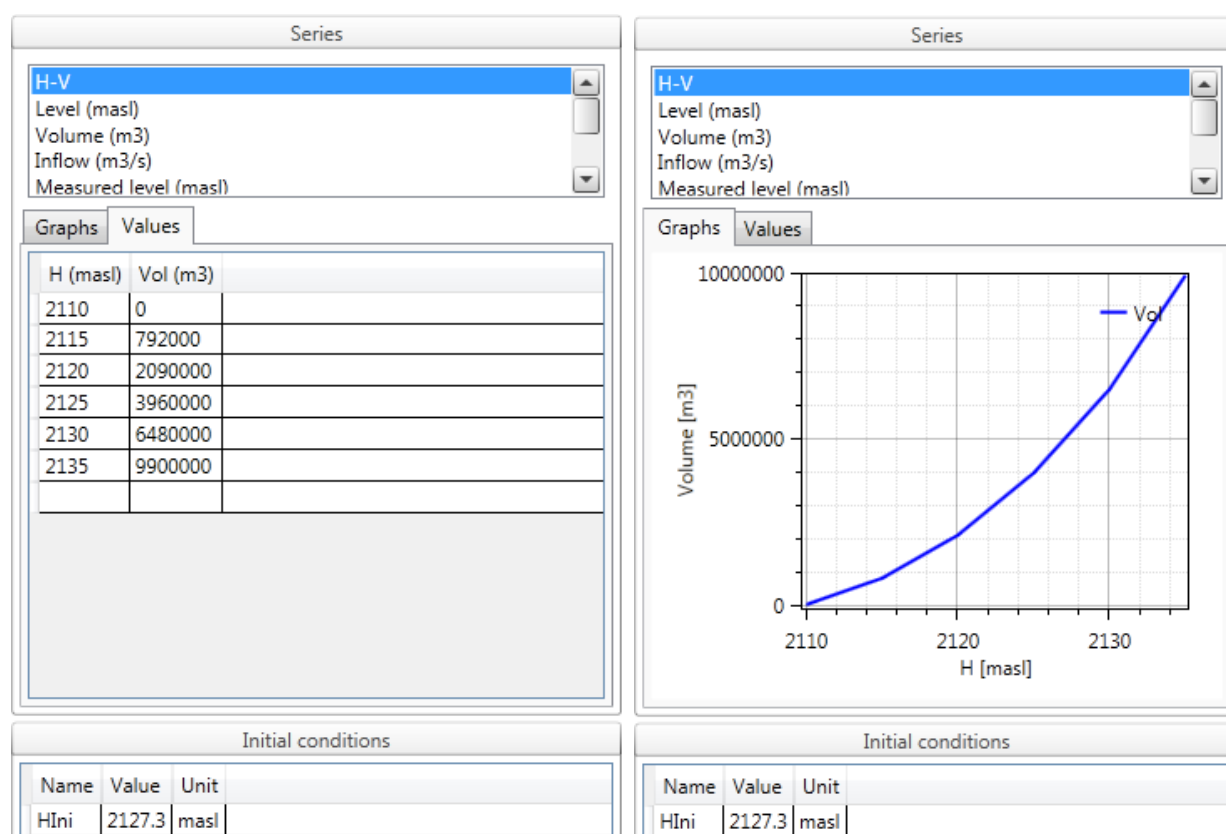


Figure 93 Relation H-V of the Reservoir 1

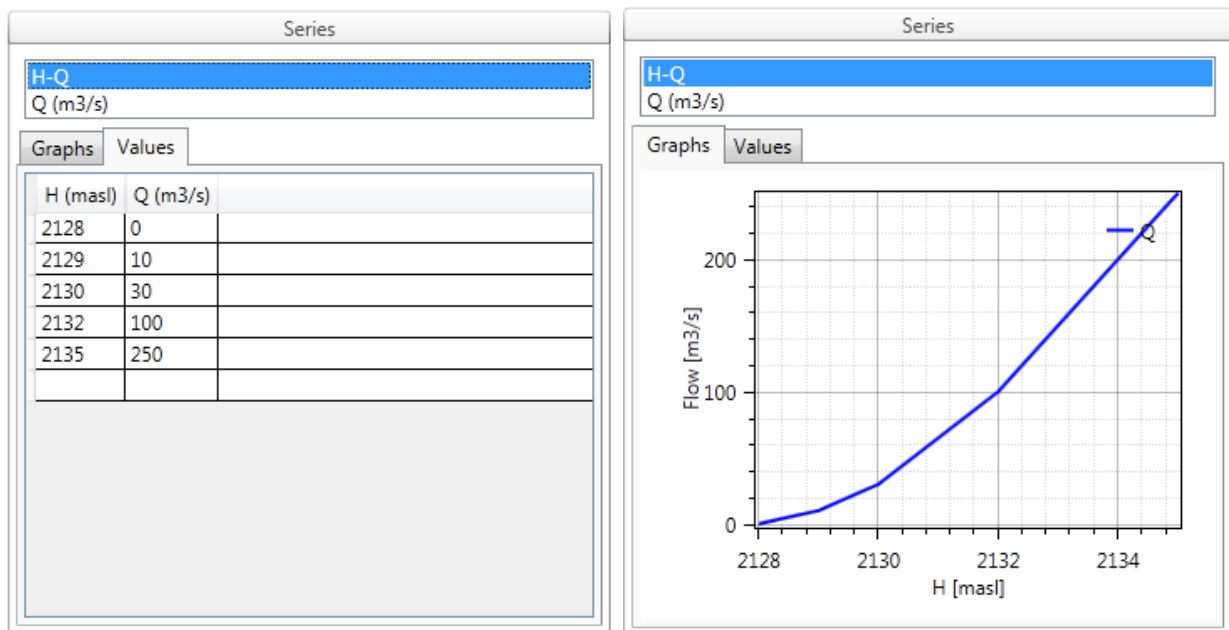


Figure 94 Relation H-Q of the HQ 1

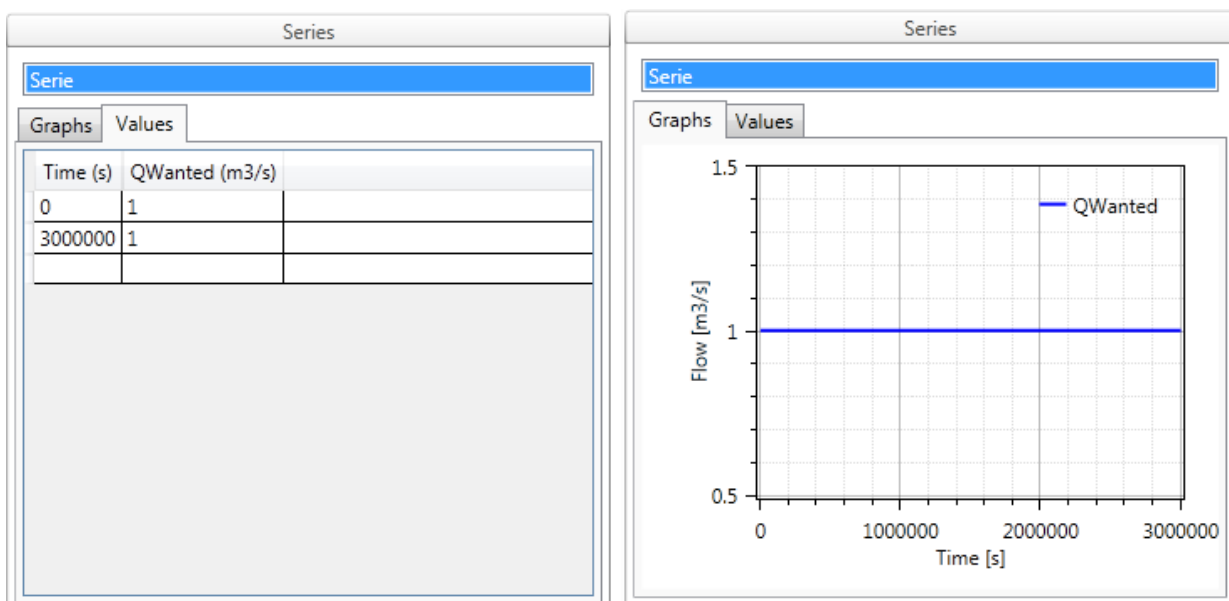


Figure 95 Discharge of the Turbine 1 inserted in the Time Series 1

Once the construction finished, it can be saved clicking in the button  and giving a name to the .rsm file (e.g. "Example3.rsm").

Before starting the calculation, the meteorological data have to be loaded: the dialog box of the database is opened clicking in  Open for loading the corresponding database file ("Database manual"). The user can click in  for visualizing or modifying the database (Figure 80).

Finally, the necessary parameters of the simulation are chosen in the menu Solver frame according to the propose dates in the wording. The other values (time intervals) stay as indicate in the program, being 600 s in both cases.

If the pre-simulation validation allows to valid the model (with the message: “Model ‘Example 3’ is valid”), the simulation can be initiated clicking in the button Start.

Results of Example 3 – Part A

All the results can be visualized by double clicking in the corresponding object. Figure 96 presents the hydrograph at the system outlet.

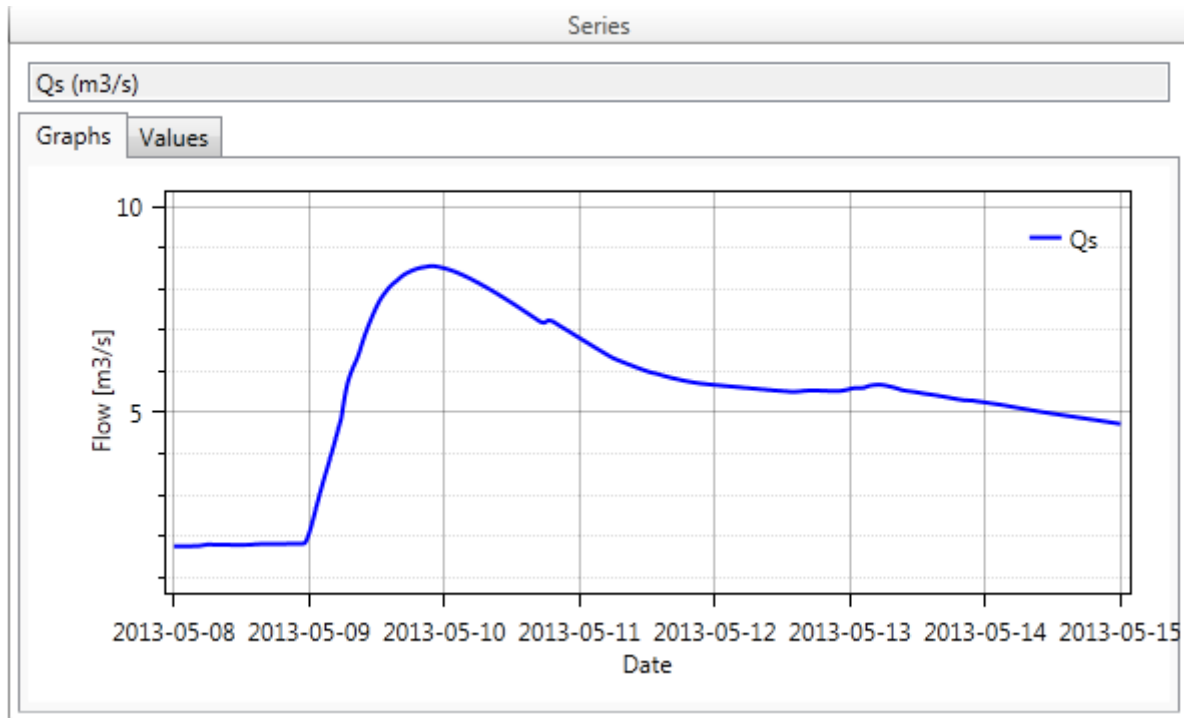


Figure 96 Outlet hydrograph

The peak discharge arrives on Mai 9, 2013 at 21:50 and the peak discharge is equal to $8.50835 \text{ m}^3/\text{s}$.

To summarize the simulated balance of Reservoir 1, an analysis of inputs/outputs in the Reservoir 1 is realized with the Plot tool. The inflow into the Reservoir 1 (Confluence), the spillway discharge (HQ 1), the turbine flow (Turbine 1), the total flow at the downstream of the reservoir (River C, Qup) and the reservoir level evolution (Reservoir 1) are presented in Figure 97. Despite the turbine, the reservoir level reached its maximal fill rating with an overflow which lasted several days. Finally the reservoir level comes around 90 cm above the initial level.

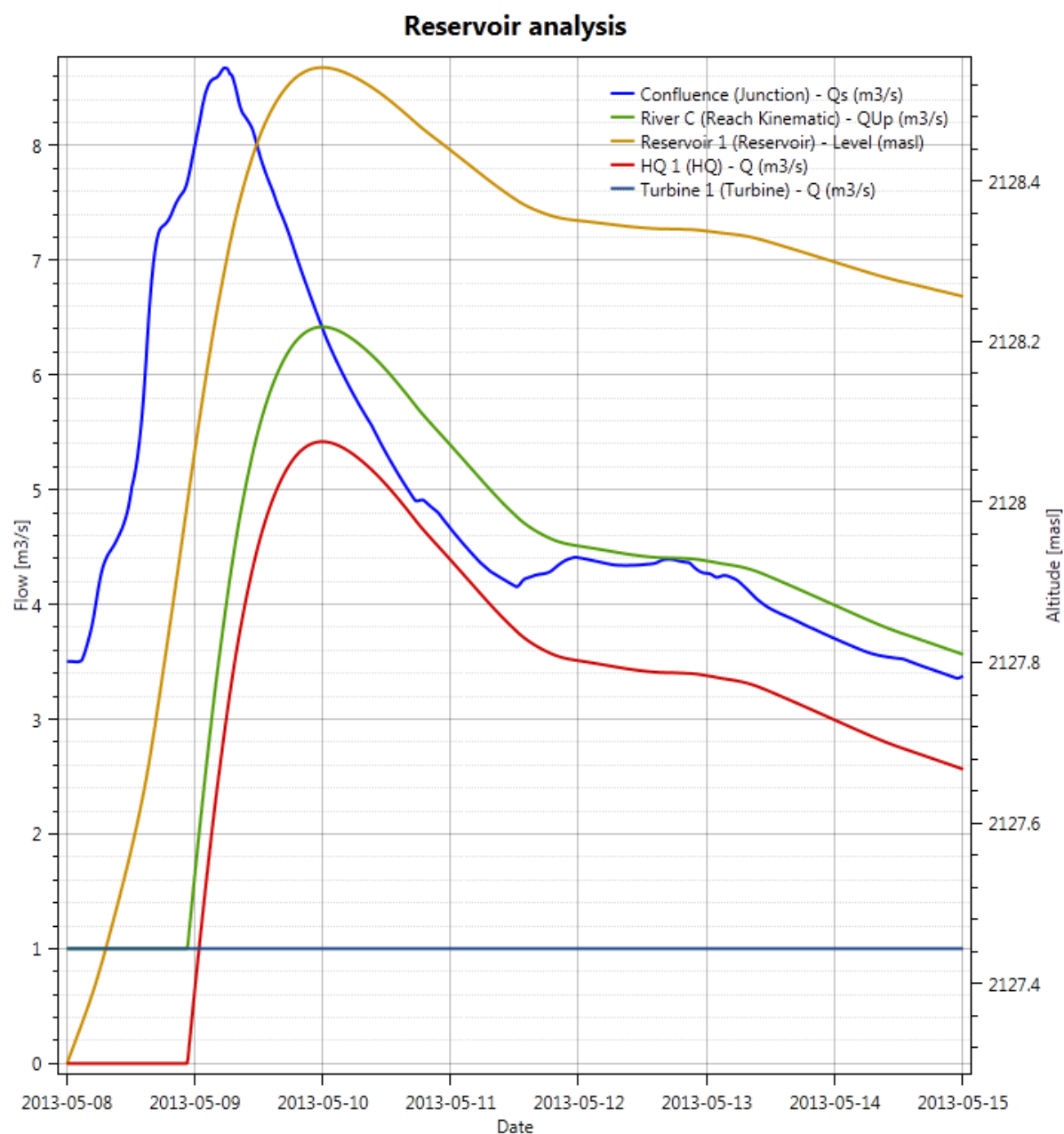


Figure 97 Flows balance of the reservoir

Resolution of Example 3 – Part B

In order to create an outlet or a facility for releases one way is to define a turbine connected to the reservoir (Figure 98). We create a new turbine and make the connections from the reservoir to the new turbine and from the turbine to river C. Also we create a time series element connected to the new turbine where we will define the releases from the reservoirs.

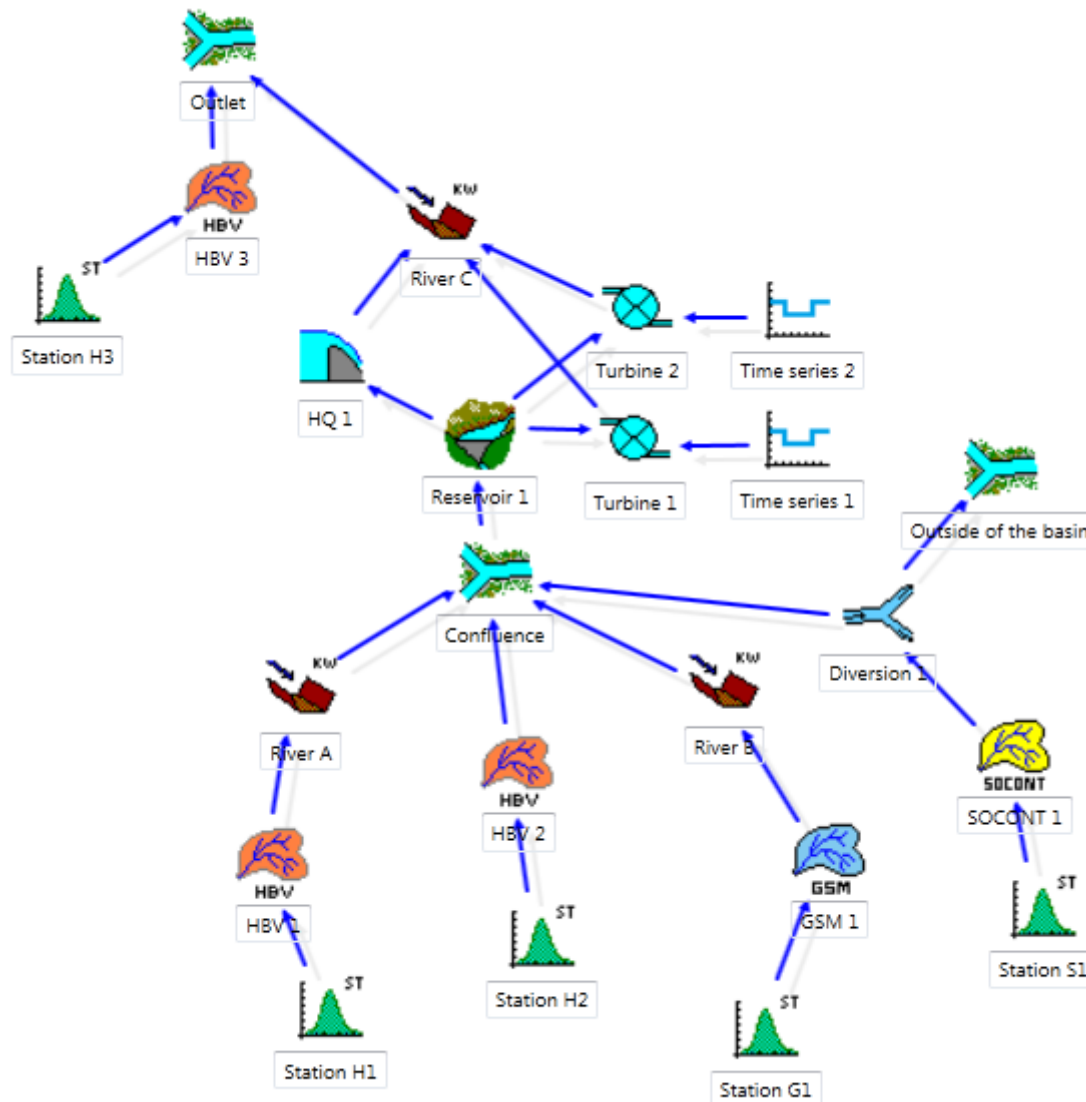


Figure 98 Typology of the model including the new release

Notice that actually the new turbine is representing a sluice of the reservoir. The advantage of this element over the H-Q element is that we can define the flow that we want release depending on the time and not on the volume of the reservoir.

Once the model has been adapted we have to define the preventive releases in the corresponding time series. Analyzing the results of the example one can think that preventive release should start near 13h of first day and finish eleven hours later.

As in the time series we have to define time in seconds (0 seconds corresponds to the start time of the simulation), the start is at 46800 s and the end at 86400 s. The value of the

releases depends on the capacity of the sluice and the decision of the manager. In this case, a discharge of $5 \text{ m}^3/\text{s}$ is defined, as presented in Figure 99.

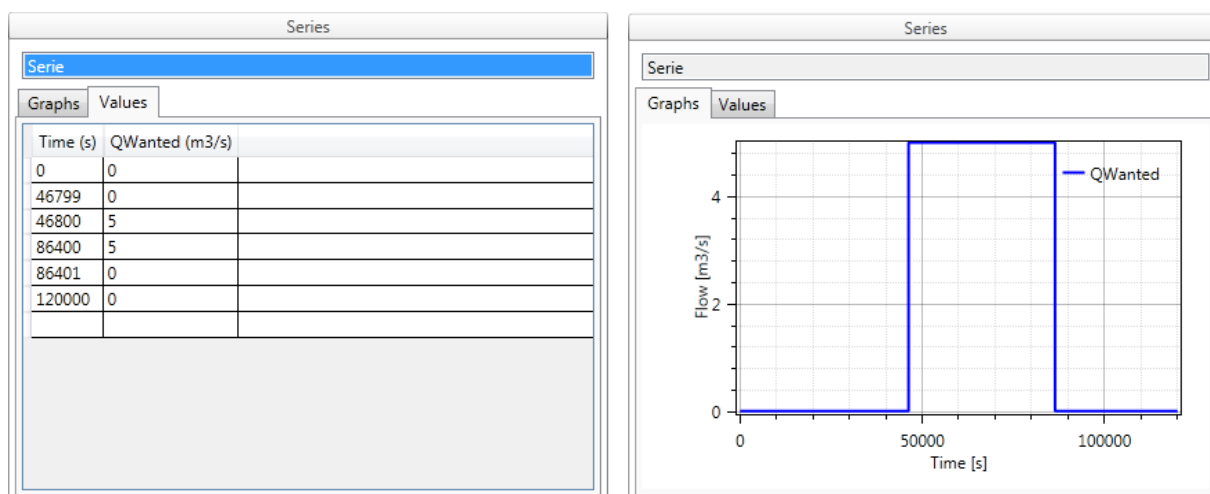


Figure 99 Proposed release from the Time Serie

New objects are linked as before, from upstream to downstream, obtaining same relations, as presented in Figure 100.

Turbine 2 relations

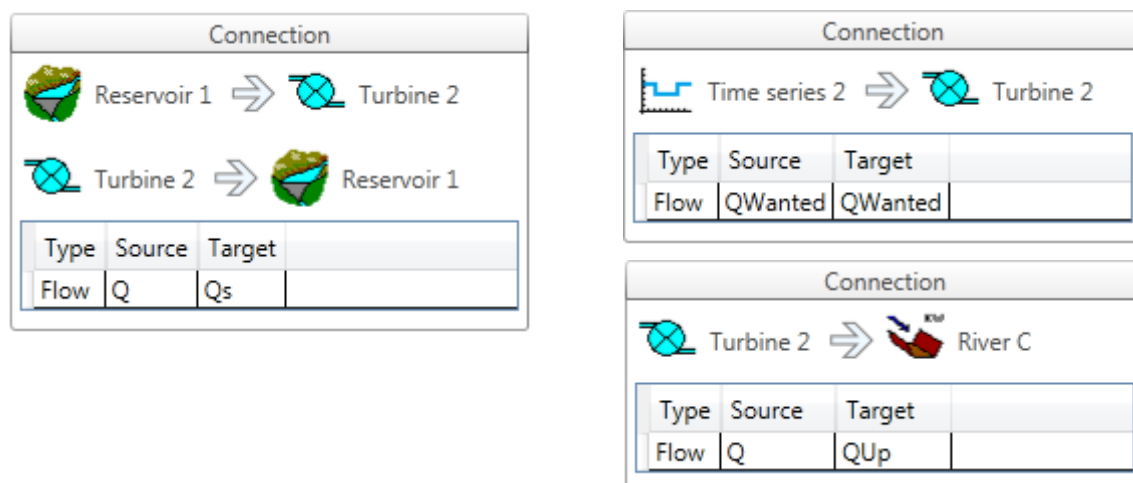


Figure 100 Connections between objects

Results of Example 3 – Part B

In the following figure we can see the new flows of the outlet and other variables. As it can be seen the peak is reduced to less than $8 \text{ m}^3/\text{s}$ due to the preventive releases at the outlet of the model (Figure 101). Moreover, with the extra releases, we have created a first artificial peak.

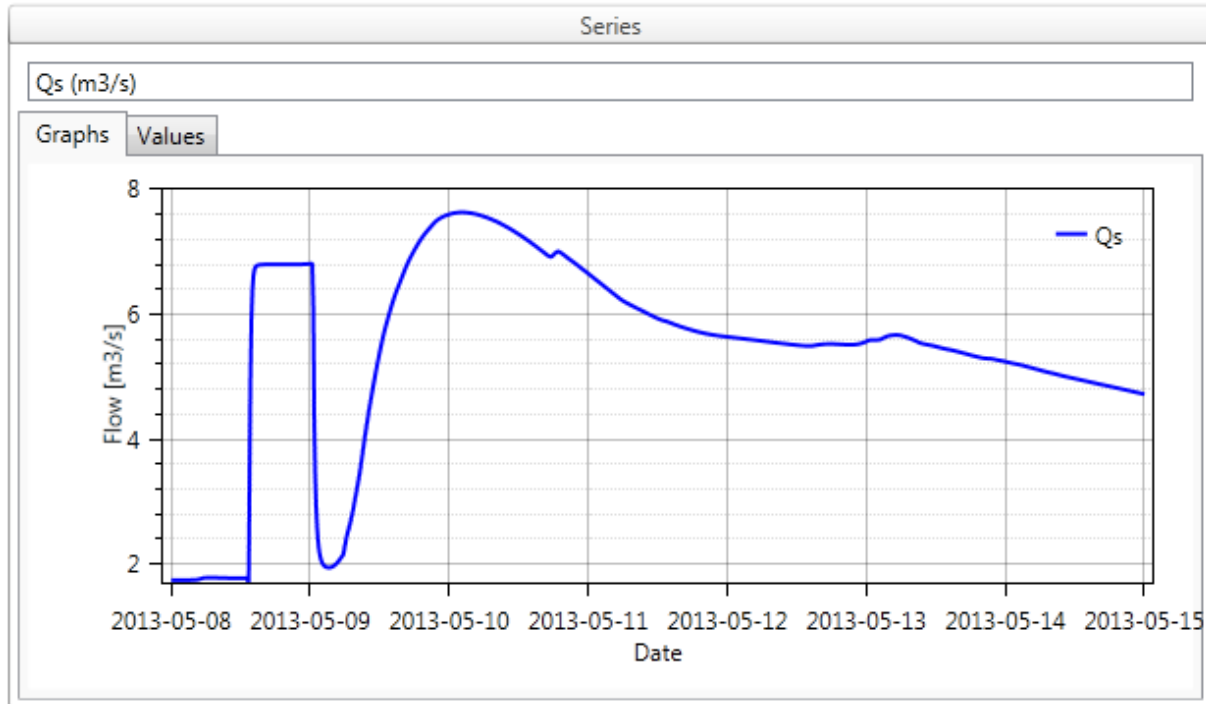


Figure 101 Outlet hydrograph after the addition of the new release. Peak discharge of $7.6171 \text{ m}^3/\text{s}$ arrives now on May 10, 2013 at 02:10.

Maximum water level on the reservoir, 2128.4731 m a.s.l., is at this case smaller than without the extra release of Part A (maximum water level of the part A was 2128.5383 m a.s.l.).

To compare these results with the results of Part A, the same results are presented, i.e., an analysis of inputs/outputs in the Reservoir 1. The inflow into the Reservoir 1 (Confluence), the spillway discharge (HQ 1), the turbine flows (Turbine 1 and Turbine 2), the total flow at the downstream of the reservoir (River C, Q_{up}) and the reservoir level evolution (Reservoir 1) are presented in Figure 102.

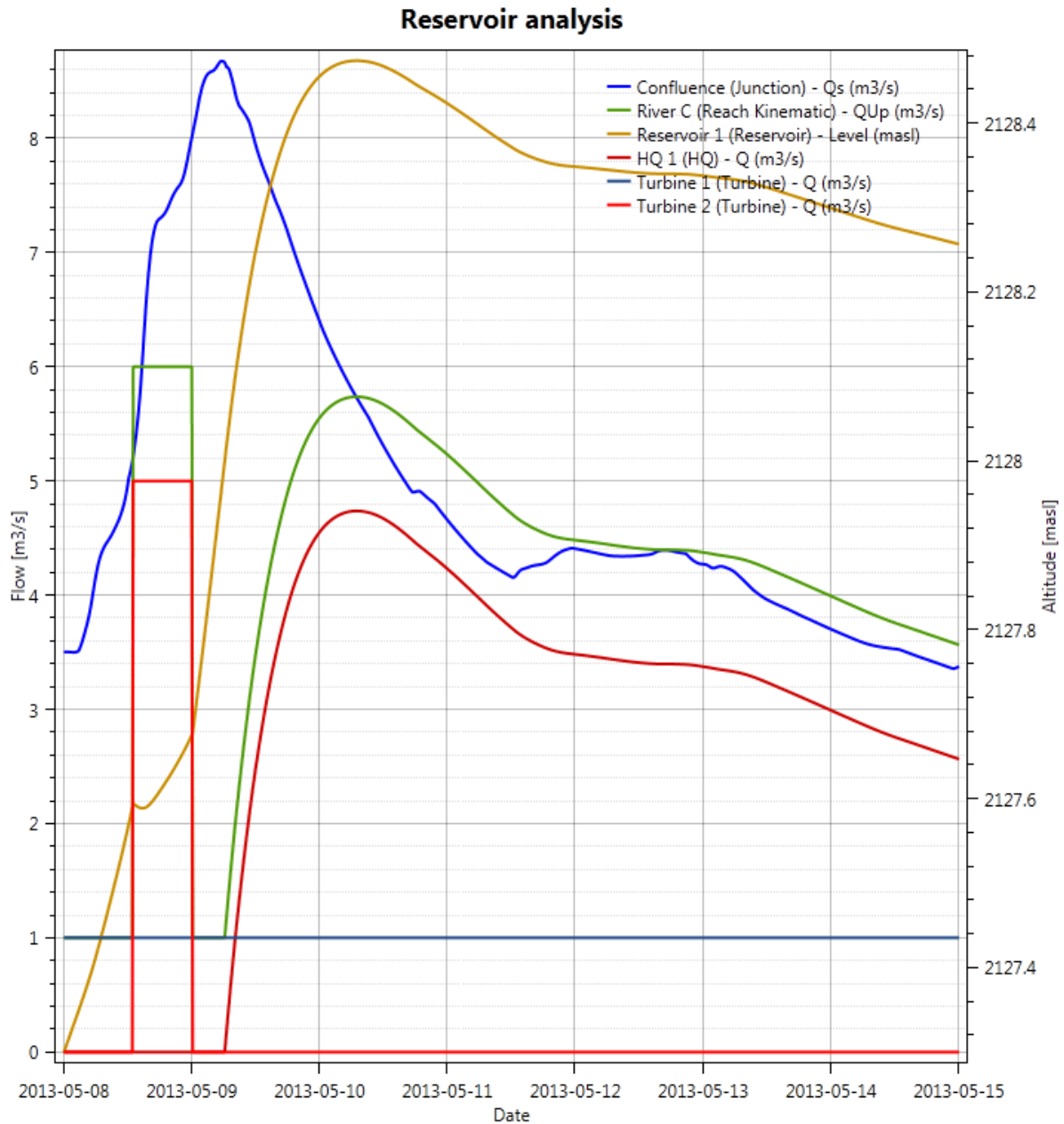


Figure 102 Flows balance of the reservoir and hydrographs at main control points

Although the objective has achieved, many issues emerge from the management of the reservoir. How much water do we have to release? Are we aggravating the situation downstream? How much energy will we lose if the flood is not as important as expected? And so on.

9.4 Example 4 – Automatic calibration of a model

This example allows an introduction to the use of the module of hydrologic calibration in RS Expert. The model starts with the previous model built in Example 2, with the same parameters.

Through this example (Figure 103), five parameters are calibrated. Two parameters are calibrated for the GSM object and three for the HBV model:

- GSM-An, the degree-day snowmelt coefficient;
- GSM-Agl, the Degree-day icemelt coefficient;
- HBV-FC, the maximum soil storage capacity;
- HBV-SUMax, the upper reservoir water level threshold;
- HBV-Kr, the near surface flow storage coefficient.

The range of values for the calibration can be defined based on the values given as regular range in Appendix 1. The temperatures, the precipitations and the outflow observed are in the database “Database manual”. A uniform and null ETP is assumed for this example (the user can check the selected ETP method in the RS MINERVE settings).

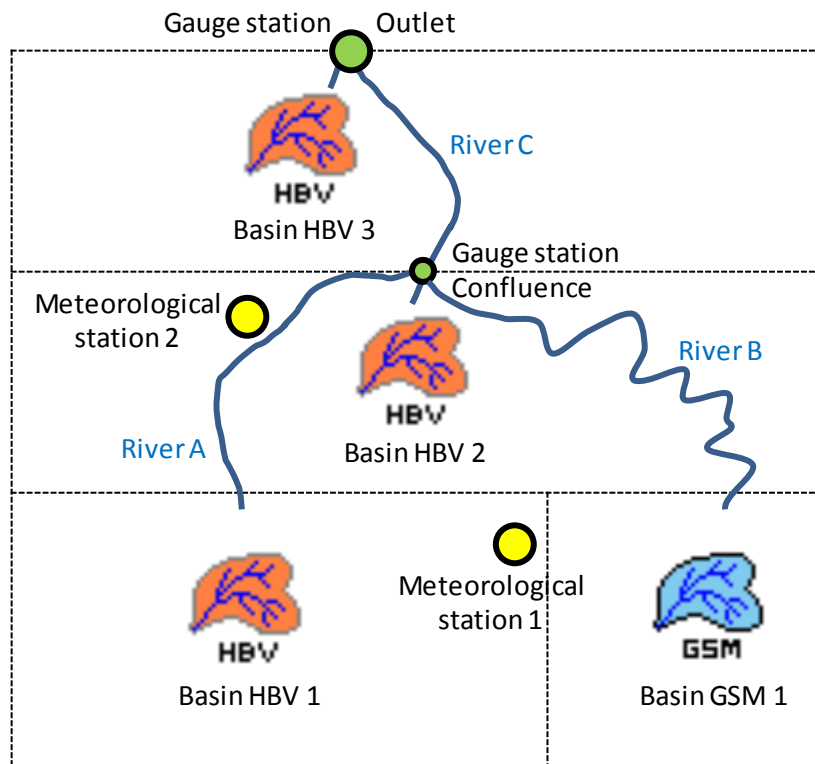


Figure 103 Model scheme

Objective of Example 4

The wanted result is the new values for the calibrated parameters of the GSM and HBV models after the automatic calibration. For the calibration, observed and simulated data are compared at the confluence point and at the outlet for a period between the 01.09.2011 00:00 and the 31.08.2012 00:00. In this example, the calibration uses an Objective Function (OF) with a weight of four for the Nash indicator, two for the Pearson Correlation Coeff indicator, four for the Relative Volume Bias indicator and zero for the other indicators. The “Simulation time step” and the “Recording time step” are fixed to 600 s.

Resolution of Example 4

For the calibration, it is necessary to add two source objects  to have a reference flows (observed discharges) at the confluence point and at the outlet. Two comparators objects  are also necessary to compare the results of the simulation with the reference data (observations) coming from the source object.

The Confluence and the Source 1 are connected to the comparator 1. The Outlet and the Source 2 are connected to the Comparator 2. The relations created can be visualized by double clicking on each blue arrow (Figure 104, Figure 105, Figure 106).

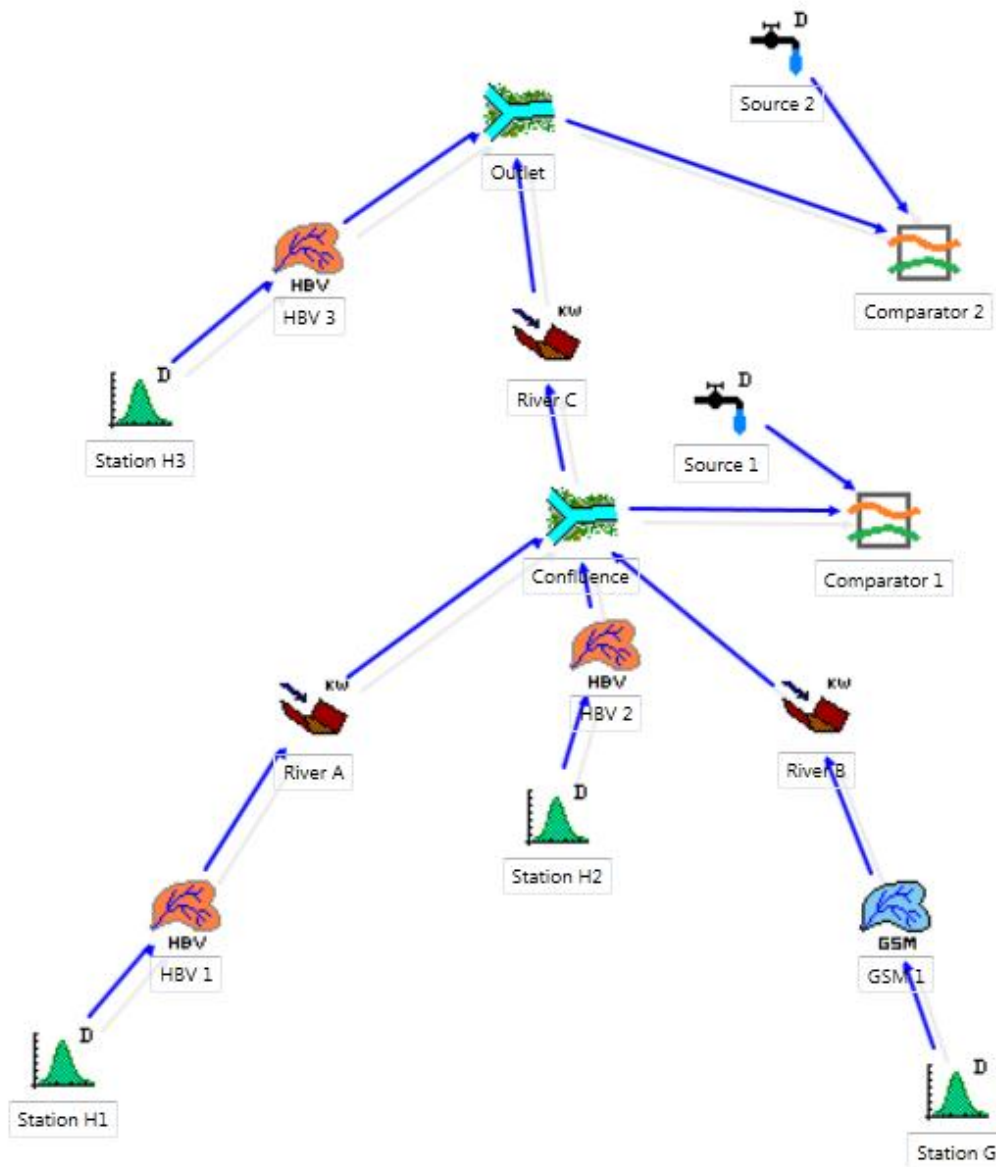


Figure 104 Topologic links between the different objects

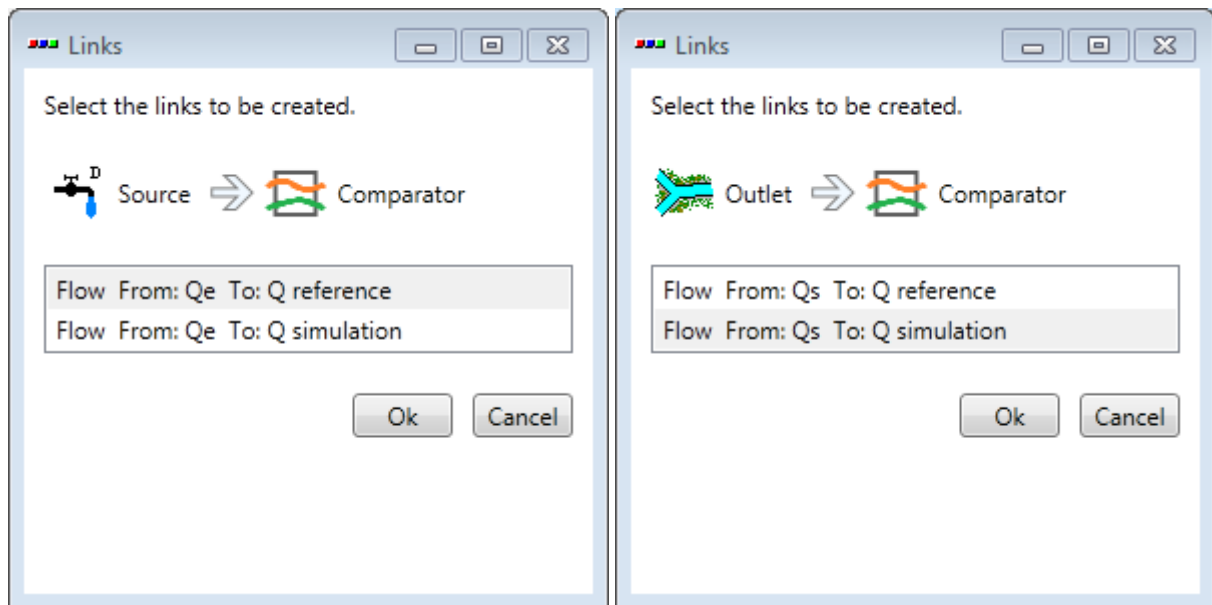


Figure 105 Possible outputs transfers between objects

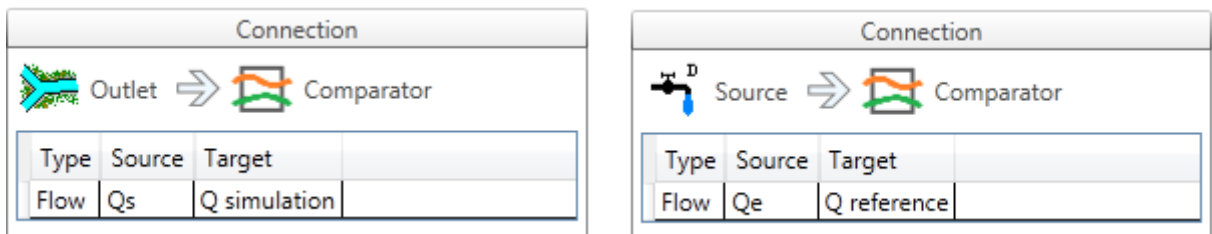


Figure 106 Connections between objects

Constructed model can be now saved clicking in the button  and giving a name to the .rsm file (e.g. "Example4.rsm").

Next, the meteorological data have to be loaded: the dialog box of the database is opened clicking in  (Figure 107) for loading the corresponding database file ("Database manual.dbx").

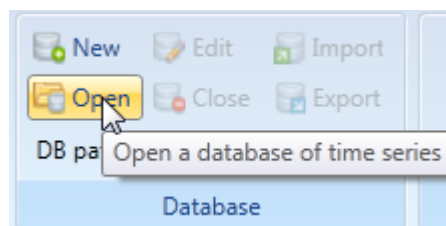


Figure 107 Database frame

The user can click in  for visualizing or modifying the database (Figure 108).

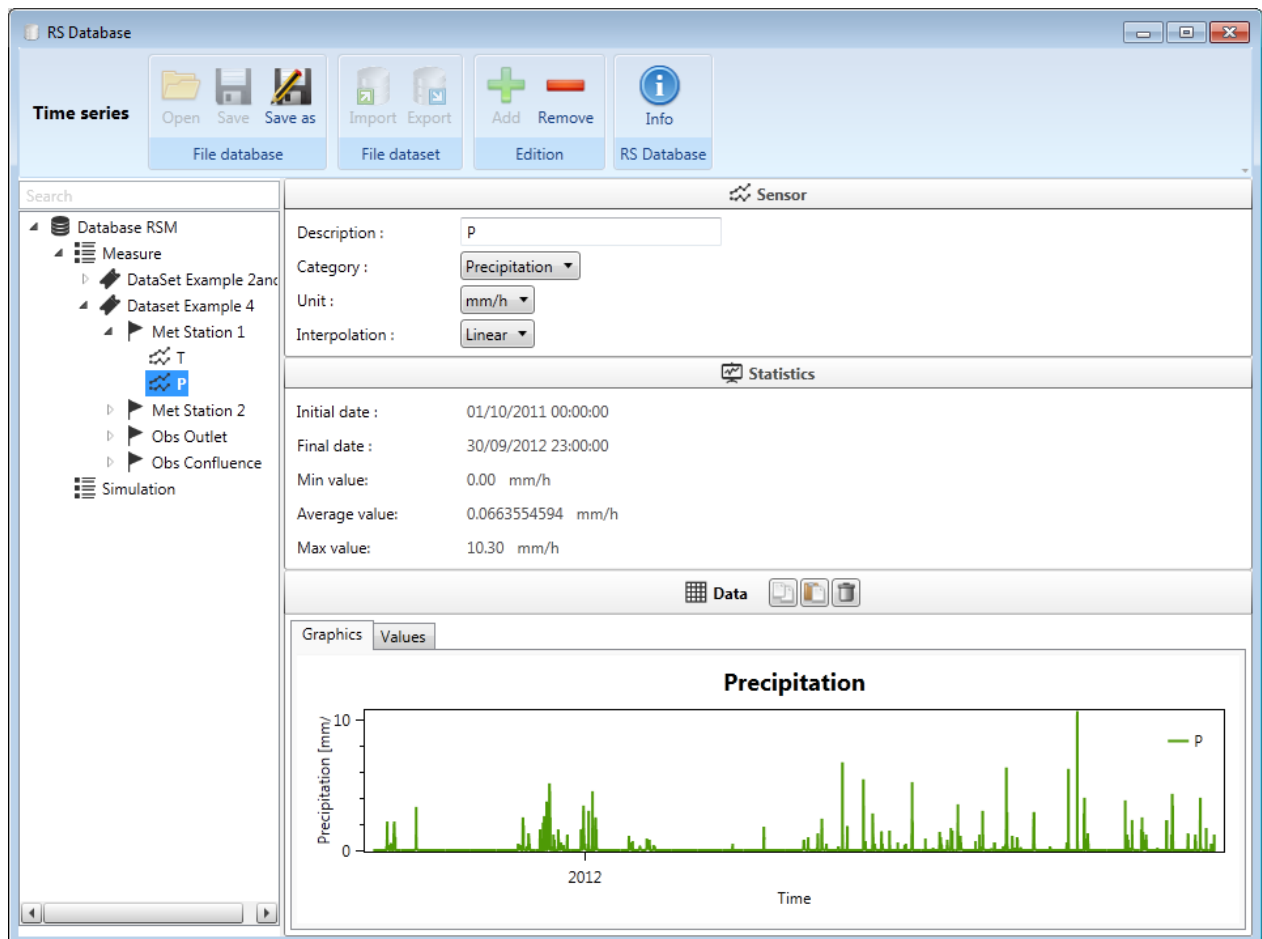


Figure 108 Database of the model

Once the database loaded, the user can connect the database to the hydrological model. For achieving this purpose, the user has to choose the correct data source in the corresponding frame (Figure 109): the group “Measure” and the dataset “DataSet Example 4” for the current example.

⬆ Data source

Name	Group	DataSet	
Station	Measure	DataSet Example 4	
Source	Measure	DataSet Example 4	

Figure 109 Data source used for connecting the model to the database

Finally, the module of hydrologic calibration in RS Expert can be launched by clicking on RS Expert in the *Toolbox* frame. The RS Expert is opened. By default, the Hydrological calibration interface is showed (Figure 110).

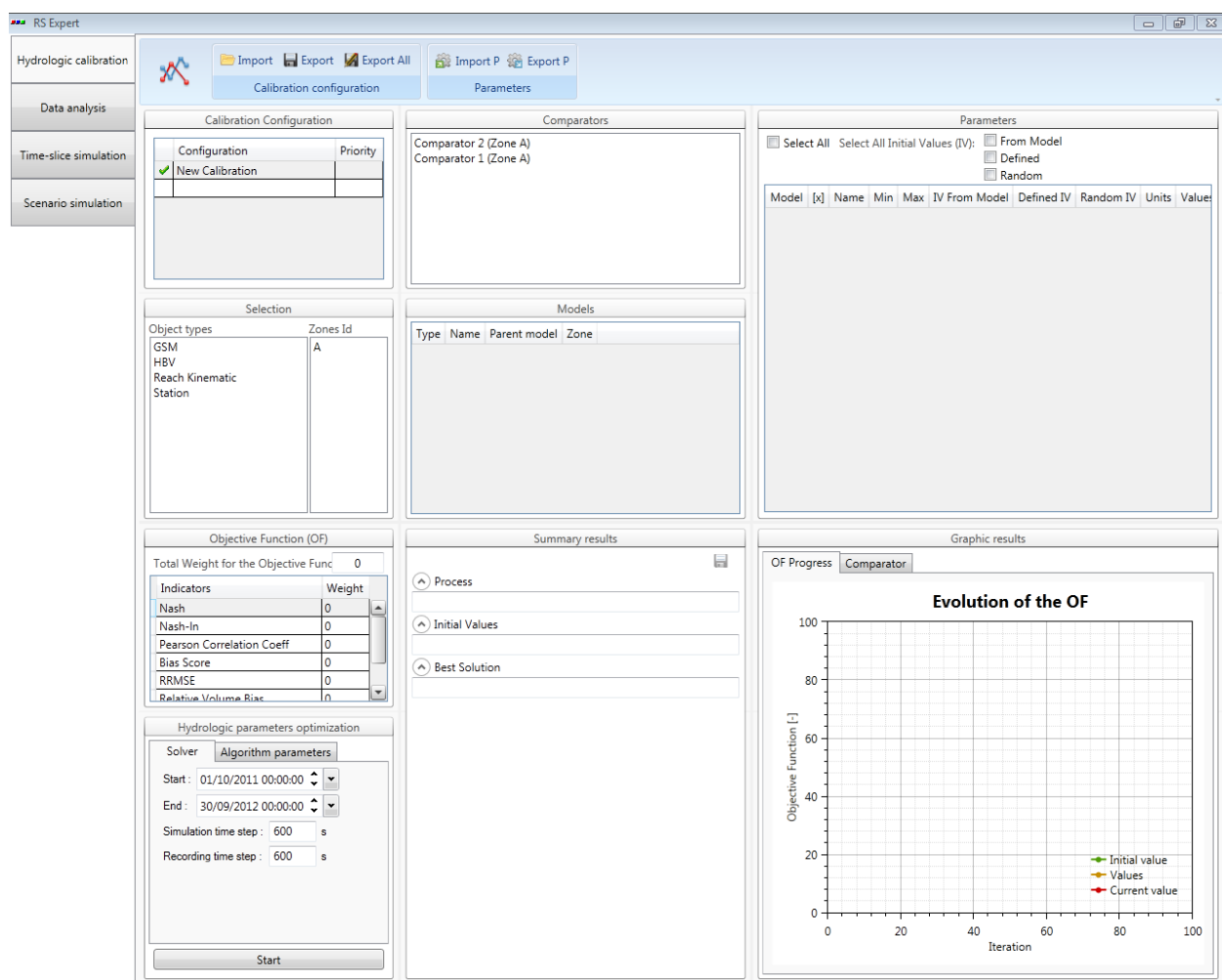


Figure 110 Interface of the Hydrological calibration module

Two calibration configurations can be created, one for each zone of the model (Figure 111). Give the order 1 to the calibration of zone 1 and order 2 to the calibration of zone 2.

Calibration Configuration		
	Name	Order
✓	Confluence	1
	Outlet	2

Figure 111 Creation of the calibration configurations

In the Selection frame the HBV and GSM objects types are selected with the corresponding zone (Figure 112).

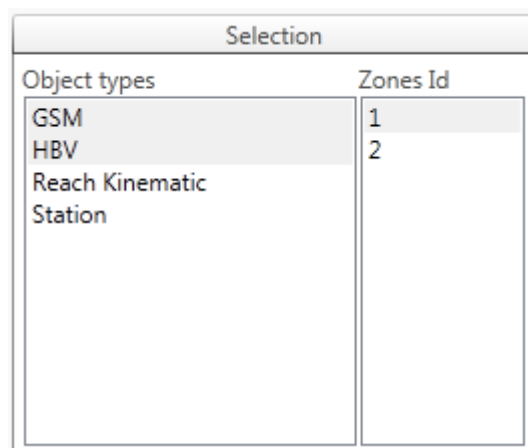


Figure 112 Selection of objects and zones to calibrate

The parameters to calibrate are checked in the Parameters frame (Figure 113). For each of them, the minimum and maximum values are defined based on the values given as regular range in Appendix 1. The source of the initial values is selected as random for the parameters to calibrate and from model for the others.

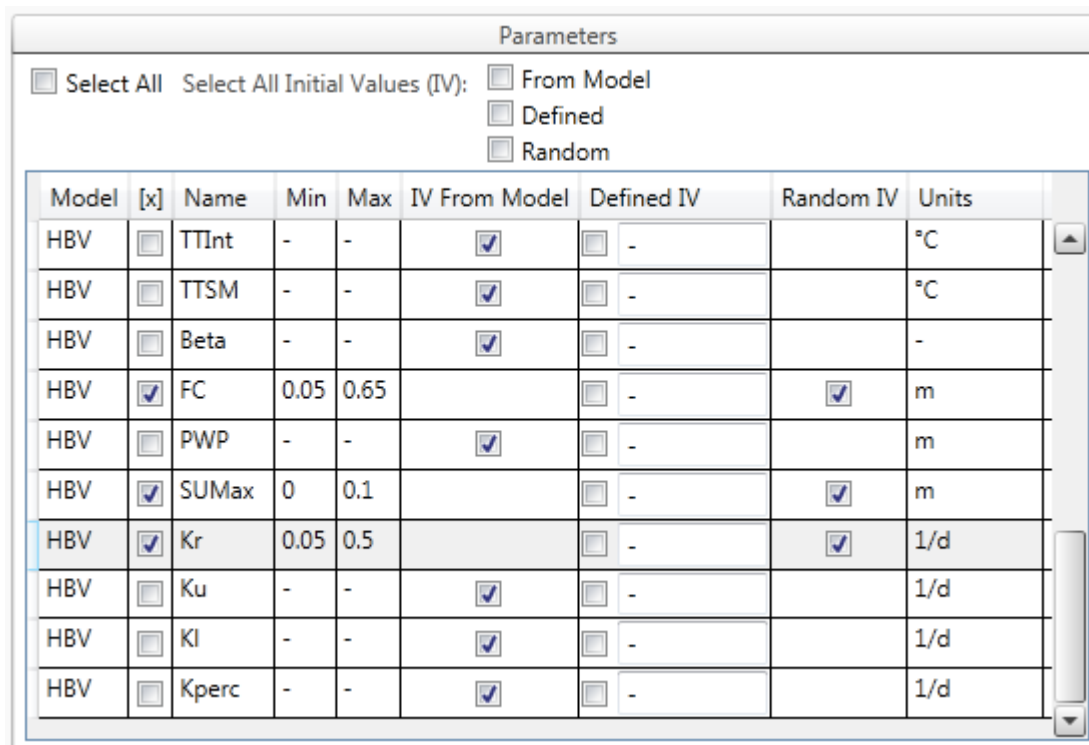


Figure 113 Definition of the parameters to calibrate

Select in the Comparator frame the comparator whose the observed discharges will be used for the calibration of the corresponding zone.

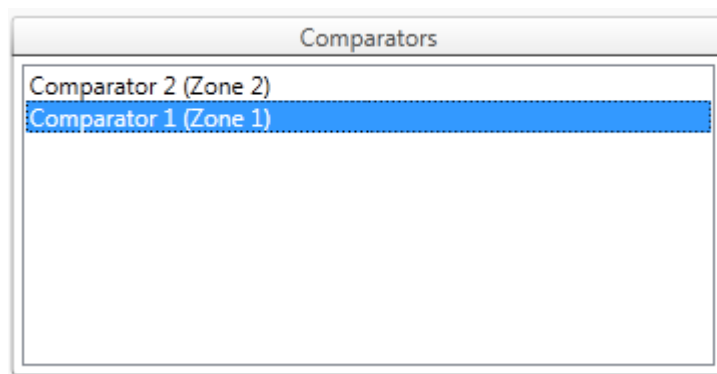


Figure 114 Selection of comparators

In the Objective Function (OF) frame the weight of the Nash and Relative Volume Bias coefficient are settled to 4 and the weight of the Pearson relative coefficient is 2. The other coefficients are all settled to zero (Figure 115).

Objective Function (OF)	
Total Weight for the Objective Func	10
Indicators	Weight
Nash	4
Nash-In	0
Pearson Correlation Coeff	2
Bias Score	0
RRMSE	0
Relative Volume Bias	4
Normalized Peak Error	0

Figure 115 Weight of each indicator to determine the objective function

After specifying the calibration period in the Solver tab of the Hydrologic parameters optimization frame, the calibration configuration can be saved and then started.

At the end of the calibration (approximately after 1000 to 1500 iterations for this example) the final parameters obtained are collected in the current model. If the model is saved, the parameters are stored; if not, the hydrological model keeps preliminary parameters

Results of Example 4

Once the calculation is finished (after approximately 1'200 iterations for the confluence calibration and 500 iteration for the outlet calibration), the best values obtained for the parameters can be visualized in the Summary results frame. From a maximum possible value of the Objective Function (OF) of 6, the best score provided by the algorithm is 5.092 and 5.089 for the confluence calibration and the outlet calibration, respectively.

Hereafter (Table 13 and Table 14) the results of the calibration (since the algorithm contains the random calculations, it is possible to obtain a similar but not exactly the same result).

Table 13 Calibrated parameters

	Initial Parameter		Best Parameter	
	Confluence	Outlet	Confluence	Outlet
GSM - An	6	-	1.98	-
GSM – Agl	7	-	0.68	-
HBV – FC	Different values	0.25	0.49	0.64
HBV – SUMax	Different values	0.05	0.029	0.053
HBV – Kr	Different values	0.25	0.24	0.24

Table 14 Performance indicators

	Initial Performance		Final Performance	
	Confluence	Outlet	Confluence	Outlet
Nash	-28.27	0.80	0.82	0.84
Nash-In	-2.91	0.79	0.80	0.82
Pearson	0.58	0.91	0.91	0.92
Correlation Coeff				
Bias Score	-10.20	0.99	0.99	0.99
RRMSE	4.08	0.33	0.32	0.29
Relative Volume	3.35	0.12	5.67	0.02
Bias				
Normalized Peak Error	0.72	-0.14	-0.18	-0.15
OF	-125.30	4.53	5.092	5.089

The simulation fits pretty well the outflow observed (Figure 116). Since, the new parameters after the calibration can be kept by saving the model.

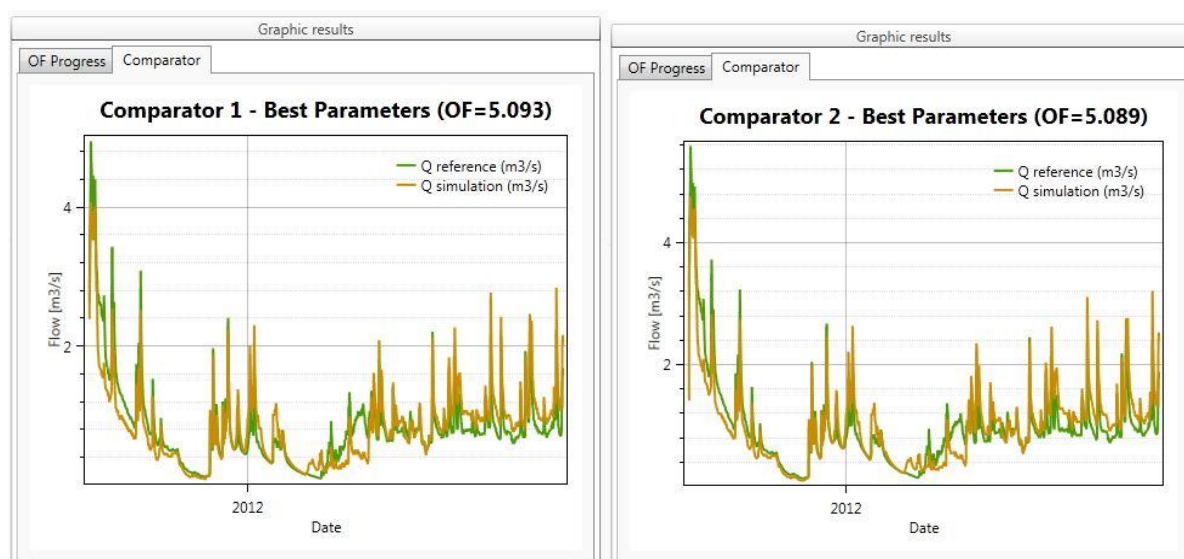


Figure 116 Graphic results of the calibration. Hydrograph of both observed and current simulated discharge

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Appendix: List of parameters and initial conditions

Table A1.1 List of parameters and initial conditions for meteorological stations and reaches

Object	Name	Units	Description	Regular Range
Station	X, Y, Z	-	Coordinates of the virtual weather station	-
	Search radius	m	Search radius of weather stations	>0
	Gradient P	m/s/m	Precipitation gradient	- ^a
	Gradient T	°C/m	Temperature gradient	-0.007 to -0.004
	Gradient ETP	m/s/m	Potential evapotranspiration gradient	- ^a
	Coeff. P,		Multiplying correction coefficient	0.5 to 2
	Coeff. T,		Adding correction coefficient	-2 to 2
Reach	Coeff. ETP	-	Multiplying correction coefficient	0.5 to 2
	L	m	Length	>0
	B0	m	Width of the channel base	>0
	m	-	Side bank relation coeff. (1H/mV)	0.1 to 1
	J0	-	Slope	>0
	K	m ^{1/3} /s	Strickler coefficient	10 to 90
	nSec	-	Number of sections (St. Venant only)	>0
	QIni	m ³ /s	Initial discharge	-

^a The precipitation and potential evapotranspiration gradients are function of the local conditions. Their regular ranges have to be estimated for each studied case.

Table A1.2 List of parameters and initial conditions for basic hydrological objects

Object	Name	Units	Description	Regular Range
Snow-GSM	An	mm/°C/day	Degree-day snowmelt coefficient	0.5 to 20
	ThetaCri	-	Critical relative water content of the snow pack	0.1
	bp	day/mm	Melt coeff. due to liquid precipitation	0.0125
	T _{cp1}	°C	Minimum critical temperature for liquid precipitation	0
	T _{cp2}	°C	Maximum critical temperature for solid precipitation	6
	T _{cf}	°C	Critical snowmelt temperature	0
	HIni	M	Initial snow height	-
Glacier-GSM	ThetaIni	-	Initial relative water content in the snow pack	-
	A	m ²	Surface of glacier	>0
	Agl	mm/°C/day	Degree-day icemelt coefficient	0.5 to 20
	Kgl	1/d	Release coeff. of icemelt reservoir	0.1 to 5
	Ksn	1/d	Release coeff. of snowmelt reservoir	0.1 to 5
	T _{cg}	°C	Critical glacier melt temperature	0
	QSnowIni	m ³ /s	Initial outflow of linear snow reservoir	-
GR3	QGlacierIni	m ³ /s	Initial outflow of linear glacier reservoir	-
	A	m ²	Surface of infiltration	>0
	HMax	m	Maximum height of infiltration reservoir	0 to 2
	K	1/s	Release coeff. of infiltration reservoir	0.00025 to 0.1
	HIni	m	Initial level in infiltration reservoir	-
SWMM	A	m ²	Surface of runoff	>0
	L	m	Length of the plane	>0
	J0	-	Runoff slope	>0
	K	m ^{1/3} /s	Strickler coefficient	0.1 to 90
	HIni	m	Initial water level downstream of the surface	-

Table A1.3 List of parameters and initial conditions for GSM and SOCONT objects

Object	Name	Units	Description	Regular Range
GSM	A	m ²	Surface of infiltration	>0
	An	mm/°C/day	Degree-day snowmelt coefficient	0.5 to 20
	ThetaCri	-	Critical relative water content of the snow pack	0.1
	bp	day/mm	Melt coeff. due to liquid precipitation	0.0125
	Agl	mm/°C/day	Degree-day icemelt coefficient	0.5 to 20
	Kgl	1/d	Release coeff. of icemelt reservoir	0.1 to 5
	Ksn	1/d	Release coeff. of snowmelt reservoir	0.1 to 5
	T _{cp1}	°C	Minimum critical temperature for liquid precipitation	0
	T _{cp2}	°C	Maximum critical temperature for solid precipitation	6
	T _{cf}	°C	Critical snowmelt temperature	0
	T _{cg}	°C	Critical glacier melt temperature	0
	HsnowIni	m	Initial snow height	-
	QsnowIni	m ³ /s	Initial outflow of linear snow reservoir	-
	QglacierIni	m ³ /s	Initial outflow of linear glacier reservoir	-
	ThetaIni	-	Initial relative water content in the snow pack	-
SOCONT	A	m ²	Surface of infiltration	>0
	An	mm/°C/day	Degree-day snowmelt coefficient	0.5 to 20
	ThetaCri	-	Critical relative water content of the snow pack	0.1
	bp	day/mm	Melt coeff. due to liquid precipitation	0.0125
	HGR3Max	m	Maximum height of infiltration reservoir	0 to 2
	KGR3	1/s	Release coeff. of infiltration reservoir	0.00025 to 0.1
	L	m	Width of the plane	>0
	J0	-	Runoff slope	>0
	Kr	m ^{1/3} /s	Strickler coefficient	0.1 to 90
	HsnowIni	m	Initial snow height	-
	HGR3Ini	m	Initial level in infiltration reservoir	-
	HrIni	m	Initial runoff water level downstream of the surface	-
	ThetaIni	-	Initial relative water content in the snow pack	-

Table A1.4 List of parameters and initial conditions for HBV and GR4J objects

Object	Name	Units	Description	Regular Range
HBV	A	m ²	Surface of the basin	>0
	CFMax	mm/°C/day	Melting factor	0.5 to 20
	CFR	-	Refreezing factor	0.05
	CWH	-	Critical relative water content of the snow pack	0.1
	TT	°C	Threshold temperature of rain/snow	0 to 3
	TTInt	°C	Temperature interval for rain/snow mixing	0 to 3
	TTSM	°C	Threshold temperature for snow melt	0
	Beta	-	Model parameter (shape coeff.)	1 to 5
	FC	m	Maximum soil storage capacity	0.05 to 0.65
	PWP	m	Soil permanent wilting point	0.03 to 0.65
	SUMax	m	Upper reservoir water level threshold	0 to 0.10
	Kr	1/d	Near surface flow storage coeff.	0.05 to 0.5
	Ku	1/d	Interflow storage coeff.	0.01 to 0.4
	Kl	1/d	Baseflow storage coeff.	0 to 0.15
	Kperc	1/d	Percolation storage coeff.	0 to 0.8
	HsnowIni	m	Initial snow height	-
	WHIni	-	Initial relative water content in the snow pack	-
	HIni	m	Initial humidity	-
	SUIni	m	Initial upper reservoir water level	-
	SLIni	m	Initial lower reservoir water level	-
GR4J	A	m ²	Surface of the basin	>0
	X1	m	Capacity of production store	0.1 to 1.2
	X2	m	Water exchange coefficient	-0.005 to 0.003
	X3	m	Capacity of routing store	0.02 to 0.3
	X4	d	UH time base	1.1 to 2.9
	SIni	m	Initial water content in the production reservoir	-
	RIni	m	Initial water level in the routing reservoir	-

Table A1.5 List of parameters and initial conditions for the SAC-SMA object

Object	Name	Units	Description	Regular Range
SAC-SMA	A	m ²	Surface of the basin	>0
	Adimp	-	Maximum fraction of an additional impervious area due to saturation	0 to 0.2
	Pctim	-	Permanent impervious area fraction	0 to 0.05
	Riva	-	Riparian vegetarian area fraction	0 to 0.2
	UztwMax	m	The upper zone tension water capacity	0.01 to 0.15
	UzfwMax	m	The upper zone free water capacity	0.005 to 0.10
	Uzk	1/d	Interflow depletion rate from the upper zone free water storage	0.10 to 0.75
	Zperc	-	Ratio of maximum and minimum percolation rates	10 to 350
	Rexp	-	Shape parameter of the percolation curve	1 to 4
	Pfree	-	Percolation fraction that goes directly to the lower zone free water storages	0 to 0.6
	LztwMax	m	The lower zone tension water capacity	0.05 to 0.40
	LzfpMax	m	The lower zone primary free water capacity	0.03 to 0.80
	LzfsMax	m	The lower zone supplemental free water capacity	0.01 to 0.40
	Rserv	-	Fraction of lower zone free water not transferable to lower zone	0 to 1
	Lzpk	1/d	Depletion rate of the lower zone primary free water storage	0.001 to 0.03
	Lzsk	1/d	Depletion rate of the lower zone supplemental free water storage	0.02 to 0.3
	Side	-	Ratio of deep percolation from lower zone free water storages	0 to 0.5
	AdimIni	m	Initial tension water content of the ADIMP area	-
	UztwIni	m	Initial upper zone tension water content	-
	UzfwIni	m	Initial upper zone free water content	-
	LztwIni	m	Initial lower zone tension water content	-
	LzfpIni	m	Initial lower zone free supplemental content	-
	LzfsIni	m	Initial lower zone free primary content	-

Table A1.6 List of parameters and initial conditions for structures objects

Object	Name	Units	Description	Regular Range
Reservoir	H-V (paired data)	-	Level - Volume relation	-
	Hini	masl	Initial level in the reservoir	-
HQ	H-Q (paired data)	-	Level - Spill flow relation	-
Hydropower	Q- η (paired data)	m ³ /s - %	Discharge-Performance relation	-
	Z _{central}	masl	Hydropower plant altitude	10-1'000
	L	m	Length of the pipe	10-10'000
	D	m	Diameter of the pipe	0.1-5
	K	m	Roughness of the pipe	0.002-1
	ν	m ² /s	Kinematic viscosity	0,6*10 ⁻⁶ -1.5*10 ⁻⁶
	Default Price	euro/Kwh	Default price, only used if no data exists in the database	0.05-0.5
Diversion	Q _{up} -Q _{diverted} (paired data)	-	Inflow - Diverted flow relation	-
Consumer	Default QDemand	m ³ /s	Default demand of consummation, only used if no data exists in the database	-
Structure efficiency	Efficiency	-	Efficiency coefficient of the structure	-

Table A1.7 List of parameters and initial conditions for structures objects

Object	Name	Units	Description	Regular Range
Time Series	Series (paired data)	s - (depending on the series)	Time – Value series	-

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